THE EFFECTS OF PHYSICAL EXERTION ON SIMULTANEOUS COGNITIVE PERFORMANCE

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THE EFFECTS OF PHYSICAL EXERTION ON SIMULTANEOUS COGNITIVE PERFORMANCE

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

SUMMARY

A simple reaction task (SRT) and a three-stage, choice reaction task (TSCRT) were used to detect changes in psychomotor performance, as measured by reaction time and error rate, prior to, during, and after exercise. Whole-body exercise on a bicycle ergometer at three pedal forces (12.64, 21.07, and 29.49 lbs.) at three pedal rates (30, 60, and 90 rpm) were investigated. Eleven male, volunteer subjects were used.

The study was designed to detect the effects of the following on cognitive performance.

1. Untrained and trained subjects
2. Pre-exercise, exercise, and recovery
3. Exercise or no-exercise
4. Pedal force
5. Pedal rate
6. Subject difference

A significant subject effect was detected on the performance of both tasks. Reaction time on the TSCRT was affected by learning. Error rate on the TSCRT and reaction time on the SRT were affected by the work period. The various exercise combinations did not significantly affect cognitive performance of fully trained subjects on either the SRT or the TSCRT.

CHAPTER I

INTRODUCTION

Statement of the Problem

In both the military and the industrial environments, situations exist in which an individual is required to perform a cognitive task while he is simultaneously engaged in some form of physical activity or experiencing some other form of secondary stress. It is of importance to know exactly how the secondary stress affects the quality of performance on the primary cognitive task. Unfortunately, the literature concerning actual experimental evidence pertaining to this relationship is fragmented and inconclusive.

Objectives

This study investigates cognitive performance, as measured by reaction time and error rate, on a simple reaction task (SRT) and a three-stage choice reaction task (TSCRT) during simultaneous whole-body exercise on a bicycle ergometer. The study attempts to quantify the effects of the following on choice reaction task performance:

1. Trained and untrained subjects
2. Pre-exercise, exercise and recovery
3. Exercise or no-exercise
4. Pedal force in pounds
5. Pedal rate in revolutions per minute
6. Subject differences

Scope

A multi-task choice reaction tester was designed, constructed, and used to measure the performance on the SRT and the TSCRT at each of the nine exercise combinations obtained by using three pedal forces (12.64, 21.07, and 29.49) and three pedal rates (30, 60, and 90 rpm) on the bicycle ergometer. That is, the exercise work load was varied from 40 to 210 watts. The two cognitive tasks were used to detect changes in psychomotor performance as measured by reaction time and error rate prior to, during, and after exercise for both untrained and trained subjects. Eight subjects exercised and three subjects composed a no-exercise control group.

General Conclusions

A significant subject effect was detected on the performance of both tasks. On the TSCRT, reaction time was affected by learning and error rate was affected by the work period (pre-exercise, exercise, recovery). Reaction time on the SRT was also affected by the work period. The various exercise combinations did not significantly affect cognitive performance of fully trained subjects on either the SRT or the TSCRT.

CHAPTER II

LITERATURE REVIEW

This chapter presents an overview of human performance as it pertains to cognitive reaction tasks. Specifically, section one presents a review of several factors which affect human performance in general; section two defines movement time and reaction time; and section three reviews the previous studies which have attempted to relate physical activity and reaction time.

Human Performance

Effects of Learning and Motivation on Performance

Man's ability to perform a skilled task is strongly affected by practice and the degree to which he is motivated. Practice manifests itself into three distinct phases of learning (Fitts and Posner, 1967): in the early or cognitive phase, the individual attempts to understand the task and performance tends to be a series of individual movements, in the intermediate or associative phase, patterns of actions begin to emerge, and in the final or autonomous phase component processes become increasingly autonomous, less directly subject to cognitive control, and less subject to interference from other on going activities or environmental distractions. The distinction between the three phases of learning is "somewhat arbitrary. As learning progresses, one phase generally merges into another, so that no definite transition between them is apparent" (Fitts and Posner, 1967, p. 11).

An individual's performance also varies as a function of motivation. "One way of viewing the relation of motivation to performance has been proposed by Helson (1964) in his Hypothesis of Par. Stated simply, the hypothesis is that in most tasks individuals set for themselves some standard of excellence and are content to meet but do not strive to exceed this standard. This aspiration level is habitually set below the level of performance they are actually capable of achieving" (Fitts and Posner, 1967, p. 26). The actual placement of the standard is a function of the instructions concerning the level of performance expected, previous successful or unsuccessful experience with the task or related tasks, and knowledge of the results of others. Individuals may work closer to their capabilities when they are provided with objective criteria (feedback) of their performance relative to their own previous performance and that of others (Fitts and Posner, 1967).

There are two types of feedback: intrinsic and augmented. Intrinsic feedback is the visual, aural, and other clues and the kinesthesis information from the muscles and joints which arises naturally as a result of the movement itself. Augmented feedback is extrinsic to the individual and depends entirely on artificial cues from the environment; eg. knowledge of results provided by tester, position compared to others, time, distance remaining, etc. Feedback, intrinsic and/or augmented, can provide knowledge of results of current performance or distance between the current state and a goal, can serve as a reward providing strong motivation to continue the task, or can provide reinforcement during the learning task. Since motivation can be significantly improved through the use of feedback, intrinsic and

extrinsic feedback channels must be considered in the design of the task (Fitts and Posner, 1967).

Stress and Performance

Stress is the total demand that the environment places on an individual (Fitts and Posner, 1967). Stress on a system can be varied by changing the force, rate, temperature, noise, etc. Thus, stress has the same meaning in the field of human performance as it does in the field of engineering mechanics. Total stress can be divided into two subareas: primary stress and secondary stress.

Primary stress is a measure of the relevant stresses associated with the accomplishment of a task. The task may be stress-inducing "because of its inherent qualitative difficulty or complexity. Or, it may be stressful because it represents quantitative levels of demand which approach the organism's capacity; for example, by speeded input, by increased volume of input, by requiring quick or precise response timing, or by being of such nature and duration as to be repetitive and boring" (McGrath, 1970, p. 29-30). An individual can respond to primary stress by working faster (may gain in speed but lose in accuracy), by filtering out or disregarding part of the information (may be an effective method for handling tasks on a priority basis), by queueing or delaying information processing (may permit irregularities in input to be smoothed out), or by stopping work completely (may allow system to return to its equilibrium) (Fitts and Posner, 1967).

Secondary stress is a measure of the stresses imposed upon the individual during the accomplishment of a task. The secondary stress could be generated by heat, cold, fatigue, noise, vibration, shock,

irrelevant information, etc.

The relationship between task performance and stress can be related in either of the following ways: performance of a stressful task, performance of a task under stressful conditions, or performance of a task to cope with stress (McGrath, 1970). The performance of a stressful task is concerned with the primary stress of the task itself. The performance of a task under stressful conditions is concerned with the secondary stress which is superimposed on the primary stress. The performance of a task to cope with stress is concerned with the secondary stress generated in order to reduce, avoid, or overcome the effects of some other primary or secondary stress-producing condition: for example, building a campfire (coping stress) to provide relief from a cold night (secondary stress) while counting stars (primary stress).

The various stresses are not necessarily additive in their effect on performance. They may combine in a complex manner which could result in a greater or smaller effect on performance than either stress acting alone would have (Fitts and Posner, 1967).

Man can adapt to a wide range of stress. However, if the level of total stress is either too high or too low, the level of performance will be reduced. If the level of stress is too low, the individual becomes insensitive, bored, loses alertness, or goes to sleep; and correspondingly, performance is reduced due to errors of omission and/or responses may lack force and speed. If the level of stress is too high, the individual becomes tense, disorganized, overstimulated, or fatigued and performance is reduced due to a reduction in cue utilization or an excessive impulsion for action. Therefore, human performance is best

under conditions of intermediate levels of total stress. The above assertions are referred to as the inverted-U hypothesis (Fitts and Posner, 1967, McGrath, 1970; Welford, 1974).

The inverted-U hypothesis predicts that there is an optimal level of total stress for any given task and a departure from this optimal level, either increase or decrease, will result in a decrease in the level of performance. (Fitts and Posner, 1967; McGrath, 1970). The Yerks-Dodson Law suggests "that the optimal level of irrelevant stimulation increases as the level of task difficulty (relevant information) decreases". (Fitts and Posner, 1967, p. 36). This "suggests that the primary and secondary stress are compensatory to some degree, that is, what is important is the total level of stimulation, both relevant and irrelevant" (Fitts and Posner, 1967, p. 37). For example, a visual monitoring task (low primary stress) may be optimally performed while listening to a radio (secondary stress) which raises the total stress level to prevent boredom; on the other hand, a complex primary task which requires much concentration (eg. studying) is optimally performed under an absence of secondary stress (noise, etc.).

Activation

Another construct which closely resembles stress is activation. Activation (Duffy, 1962) and arousal refer to variations in the excitation of the individual as a whole or, specifically, the degree of metabolic activity within the various organs and tissues of the body. The level of activation varies in a continuum from a low during a deep sleep to a high during periods of extreme effort or intense excitement. Many different factors, psychological and psysiological, may affect the level of

activation; for example, physical activity, exercise, drugs, hormones, and/or emotional factors such as threat or excitement. Thus, all activity, either overt or covert, requires release of internal energy and results in an increased level of activation.

"There is an optimal level of activation for the performance of a given task at a given stage of practice, which may vary somewhat with the individual and with other aspects of the situation. If such is the case, the curve expressing the relationship between degree of activation and quality of performance would be an inverted-U shaped curve, in which increases in activation would be associated with an increase in the quality of performance up to a certain point, after which further increases in activation would be associated with increasingly inferior performance." (Duffy, 1967, p. 159)

Measurement of the level of activation presents a problem. Several psysiological factors, (such as, skin resistance, skeletal muscle tension, electrocephalogram (EEG), respiration, blood pressure, pulse rate, and body temperature) show relatively consistent changes with changes in activity and can be used as a rough indicator of the level of activation. The problem is that these factors can vary as a function of factors other than activation (age, time of day, etc.). Also, it is hard to measure most of the above factors during an individual's normal activity. Pulse rate is an often used measure, while EEG appears to be the most accurate (Duffy, 1962).

Since activation is the amount of internal activity, it may be considered to be a measure of the amount of total stress; but, on the other hand, since total stress is defined as the total load on the

individual, stress may be considered to be the determinant of the level of activation.

Individual Differences

Individuals differ greatly in their capacity to handle the demands of a situation and their ability to make the required responses. Thus, different individuals react to the same stressful situations in various ways: in some, performance is improved, while for others, performance is degraded.

One explanation for this difference is that the chronic level of activation or arousal is different among individuals (Duffy, 1962; Welford, 1974). This suggests that those individuals with the highest level of chronic arousal would tend to perform better on monotonous, low-stress tasks than would those individuals with the lower level of chronic arousal. On the other hand, since he requires less additional stress to reach his optimal level of arousal, the individual with the higher level of chronic arousal would not perform as well under high-stress conditions as the individuals with the lower levels of chronic arousal.

Another explanation for the differences in individual performance under stress may be due to the fact that, the level of stress is a function of the individual's perceived demand and his perceived ability to respond adequately (Sells, 1970). "The unavailability of a response may be due to physical inadequacy; absence of the response in the individual's response repertoire, or lack of training, equipment, or opportunity to prepare. Thus, some individuals, because of training, conditioning, habitation, prior experience, equipment, expectation, support and/or other mitigating factors which effectively reduce the

intensity of stress, may be able to perform under conditions that far exceed the capabilities of others" (Sells, 1970, p. 138). For example, two pilots who survive separate plane crashes in the artic, one with his survival gear and the other without.

Despite these genuine differences between individuals, general statements concerning the effects of stress on human performance are justified. In general, the direction and general form of human response to a given stress is the same even though the timing or magnitude of the individual response may vary greatly. (Fitts and Posner, 1967).

Signal Detection Theory

The signal detection theory (Fitts and Posner, 1967; Welford, 1974) suggests that, since the brain is dynamic and is in a continuous state of activity, any incoming stimulus signals have to be distinguished from a background of random neural firing ("noise") which already is present in the individual. The intensity of the internal noise varies from moment to moment and may form a distribution as shown in the left curve of Figure 1. The stimulus signal adds to the intensity of the noise as shown by the right distribution curve in Figure 1. The probability of detecting the new stimulus depends on its intensity relative to the intensity of the internal noise (distance "d" in Figure 1).

The signal detection theory assumes that the individual establishes some cut-off level (see Figure 1) and reports any internal activity above this level as "signal" and below this level as "no signal". A lower cut-off level will result in fewer missed signals (type I errors) but more "false reports" (type II errors). The reverse is true for a higher cut-off level. The cut-off level is established as a function of the

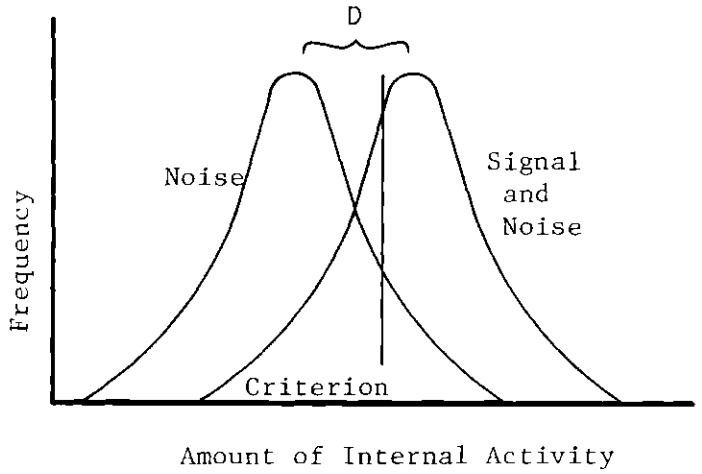


Figure 1. Signal Detection Theory
(Fitts and Posner, 1967)

instructions received, expected probability of occurrence, and expected rewards and punishments associated with type I and type II errors (Fitts and Posner, 1967).

Activity-set

During the accomplishment of a task, the individual must optimize several factors in order to maximize his level of performance. These factors are: the level of activation, the trade-off of speed and accuracy, the attention to important sources of feedback, the establishment of expectancies for up-coming events, etc. This complex pattern of adjustment has been termed the "activity-set" (Nacson and Schmidt, 1971, Schmidt and Wrisberg, 1971).

When an individual changes tasks or rests, he loses the activity-set as the systems reoptimize to his current activity. Thus, when he returns to his original task, some decrement in performance ("warm-up decrement") exists while the activity-set is being reoptimized. This performance decrement lasts for only 3 to 5 trials depending on the task (Nascon and Schmidt, 1971).

Reaction Time and Movement Time

Skilled movements may be divided into two phases. The first phase involves the preparation for movement and is termed "reaction time". The second phase includes the movement to the goal and is termed "movement time".

Movement Time

Movement time is a function of the amplitude of the movement and in the absolute precision required in terminating the movement. An index

of movement difficulty (ID) was proposed by Fitts (1954) as: $ID = Log_2 2A/W$, where A is the amplitude of movement (distance), and W is the total tolerance for error in terminating the movement (accuracy). Any factor which increases the ID causes an increase in movement time.

Reaction Time

Reaction time is the delay between the occurrence of a stimulus event and the initiation of an applicable response. It is a definite period of time during which the stimulus is detected and the response is selected. Simple reaction time is associated with a single stimulus-response condition, and choice reaction time is associated with multiple stimulus and/or multiple response conditions. Reaction time is a function of the information contained in the stimulus-response combination and of the number of sensory samples required.

A straight line appears to relate the Shannon-Weaver measure of information and reaction time (Fitts and Posner, 1967). The slope of this line (the reciprocal of which represents the rate of information transmission in bits per second) is a function of the degree of compatibility between the stimulus code and of the amount of training. The degree of compatibility established the original slope (low compatibility results in a steep slope) and as learning is increased the slope will tend to decrease (Fitts and Posner, 1967).

The signal detection theory suggests that reaction time is a direct function of the number of sensory samples required. Since the individual must detect a given stimulus from a background of "noise", he must take a sufficient number of sensory samples to reach a given level of confidence that the stimulus has, in fact, occurred. The number of

samples required is a function of the intensity of the stimulus relative to the background "noise", the known probability of a given stimulus occurring, and the level of confidence established after a compromise between speed and accuracy. The reaction time increases when the stimulus intensity or probability decreases, or when the desired accuracy increases (Fitts and Posner, 1967).

Physical Activity and Reaction Time

The inverted-U theory suggests that physical activity, which by its nature causes an increase in the level of arousal (or activation level or level of total stress), should have an inverted-U shaped relation with performance. However, the literature is inconclusive on this fact, especially in regard to reaction time (RT).

Prior Exercise

Several studies have compared the reaction time at rest with that following a period of exercise. The criterion task and level of exercise varied considerably; however, these studies strongly suggest that prior exercise does not affect reaction time. (Welch, 1970; Elbel, 1940; Phillips, 1963; Meyers, et al, 1969; Schmidt and Stull, 1970).

Babin (1966) measured RT after an exercise period of 3, 4, 5, 6, or 7 minutes on a bicycle ergometer and found RT to be best after 3, 4, and 5 minutes and worst after 7 minutes.

Concomitant Exercise

Varied results have been reported by the few studies which have considered the effects of concomitant exercise on reaction time.

Sjoberg (1968) (as reported by Gutin, 1973) measured 2-choice RT while subjects were continuing to work on a bicycle ergometer at a load

of 150, 300, 450, 600, or 750 Kgm/min after an exercise period of 5.5 minutes. "The results took a clear-cut inverted-U form with best performance occurring at the 450 Kgm/min workload" (Gutin, 1973, p. 260).

Levitt and Gutin (1971) found an inverted-U relationship between the level of activation (as measured by heart rate) and a 5-choice reaction time task. Concomitant treadmill exercise was varied to maintain a heart rate of 80, 115, 145, or 175 beats per min (BPM) during a 6 minute exercise period. The RT measurements were taken while the subjects continued to exercise. The optimal performance was obtained at a heart rate of 115 BPM and poorest performance at 175 BPM. However, the improvement at 115 BPM over the rest condition was not significant.

Levitt (1972) redesigned the above task slightly and added a 2-choice RT and a simple RT task. He did not find any significant interaction between type of RT task and level of exercise. Summed over the three RT tasks, a clearcut inverted-U curve was found, with optimal performance at the heart rates of 115 and 145 BPM and lower at 80 and 175 BPM.

Dechovitz (1974) measured the reaction time on a two-stage choice reaction time task under concomitant exercise on a bicycle erogmeter at a load of 30, 60, 120, or 180 watts. He found an upright-U relationship with reaction time being faster at 30 and 120 watts and lower at 60 and 180 watts. However, he reported that this change in RT was due to a tradeoff between speed and accuracy, since the error rate increased as RT decreased. He concluded that cognitive performance is not adversely affected by simultaneous exercise.

The above discrepancy in findings (Levitt and Gutin's inverted-U relationship on a 2.32 bit task and Dechovitz's no affect relationship on a more difficult 2-stage, 2 bit task) may possibly be explained by the stage of learning obtained by the subjects involved. Dechovitz used fully trained subjects (4500 practice trials) while Levitt and Gutin used somewhat less trained subjects (25 practice trials).

CHAPTER III

METHODS AND PROCEDURES

This chapter presents a description of the equipment, instrumentation, experimental procedures, and statistical techniques employed in this study.

Equipment and Instrumentation

Multi-Task Choice Reaction Time Tester

A multi-task choice reaction time tester was designed and constructed for use in this study. It consisted of a display unit, a response unit, and a control unit with a stimulus switch.

The display unit (Figure 2) consisted of a 15 inch by 15 inch panel which contained an arrangement of 24 lights and four LED digital displays. The four digital displays (D_1, D_2, D_3, D_4) were mounted in a horizontal row across the upper portion of the display unit. Positioned below and aligned with the digital displays were a horizontal row of green indicator lights (H_1, H_2, H_3, H_4) and a four row, four column, square matrix of red indicator lights (M_{11}, M_{12},...,M_{43}, M_{44}). On the left side of the display panel, aligned with the rows of the matrix, was a vertical column of four green indicator lights (V_1, V_2, V_3, V_4).

The multi-task choice reaction tester provided the capability to conduct a variety of choice reaction tasks varying in information content and in the degree of stimulus-response compatability. Examples of some of the choice reaction tasks (CRT) that could have been presented are the

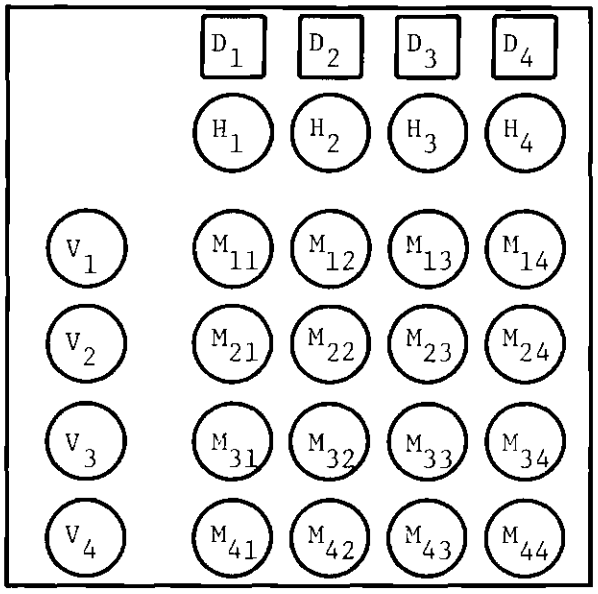


Figure 2. Pictorial of Subject's Display Panel
(not to scale)

following:

1. Simple CRT - Turn on any one light; subject presses predesignated response switch.
2. 1-bit CRT - Turn on one of two lights; subject presses corresponding response switch.
3. 1.59-bit CRT - Turn on one of three lights; subject presses corresponding response switch.
4. 2-bit CRT - Turn on one of four lights; subject presses corresponding response switch.
5. 2-bit CRT - Turn on one of four digits on a single digital display; subject presses corresponding response switch.
6. 2-stage, 2-bit CRT (horizontal) - Turn on a permutation (a combination of the four digits; such that, all are used only once in each combination) of the digits "1", "2", "3", and "4" in the digital displays and one of the green lights in the horizontal row; subject determines illuminated green light, reads digit shown on digital display directly above, and presses switch corresponding to indicated digit.
7. 2-stage, 2-bit CRT (vertical) - Turn on a permutation of the digits "1", "2", "3", and "4" in the digital displays and one of the green vertical lights; subject determines which green light is illuminated (numbered numerically from top to bottom) reads the digit shown on the corresponding digital display (numbered numerically from left to right), and presses the corresponding response switch.

8. 3-stage, 2-bit CRT - Turn on a permutation of the digits "1", "2", "3", and "4" in the digital displays, one of the green lights in the vertical row and four red matrix lights (such that one is on in each column and one is on in each row); subject determines which green light is on, scans across the corresponding row of the matrix and determines which red light is on in that row, scans up to the digit displayed in the same column, and presses switch corresponding to indicated digit.

The stimulus-response compatability of any of the above tasks could be varied by simply changing the numerical designation of the response switches (for example: 1,2,3,4 changed to 4,1,3,2). Note: the simple CRT and the 3-stage, 2-bit CRT were used in this study, and they will be discussed in detail under the procedures section of this chapter.

The subject's response unit consisted of four individual switches (S_1, S_2, S_3, S_4). When any one of the four response switches was closed, the timer would stop and the corresponding response light (R_1, R_2, R_3, R_4) on the control panel would illuminate.

The control unit (Figure 3) consisted of a system of switches which were used to control the light or combination of lights that would be illuminated on the display unit. The control panel which measured 15 by 15 inches contained the following features: a stimulus switch (SS), manual control switches (H, V, M and D), submaster switches (SM), preselect switches (P), correct response indicators (C), actual response indicators (R), and a duplicate of the subject's display.

The selected stimulus display was presented to the subject by closing the stimulus switch (lower right corner of the control panel).

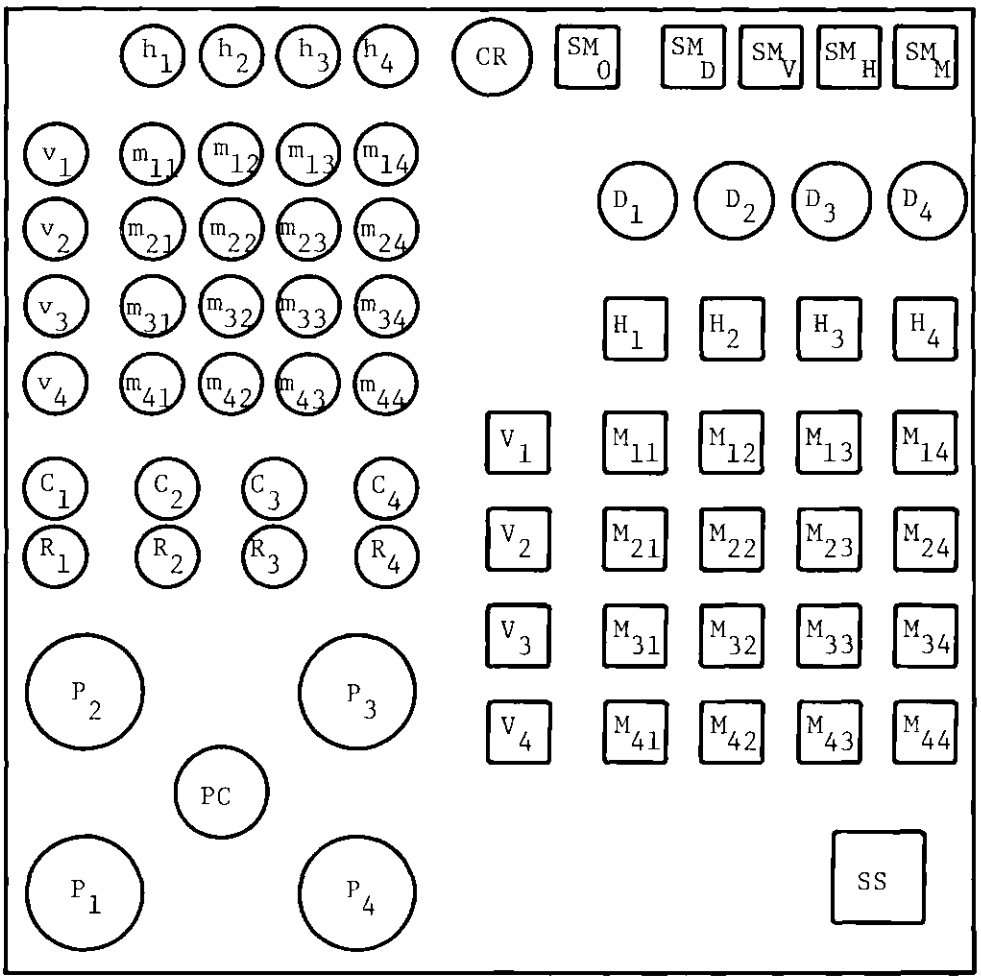


Figure 3. Pictorial of Control Panel
(not to scale)

An external stimulus switch (connected through a jack on the rear of the control unit) was also provided which allowed convenient "push-button" operation by either hand or foot.

Four submaster switches (SM_D, SM_V, SM_H, SM_M) were located on the upper right portion of the control panel. From left to right, respectively, these toggle switches controlled the power supply to the LED digital displays (SM_D), the vertical row of green lights (SM_V), the horizontal row of green lights (SM_H), and the matrix of red indicator lights (SM_M). If a submaster switch was in the off position, none of the lights of that function would be turned on when the stimulus switch was closed. The setting of these submaster switches determined which choice reaction task was presented to the subject.

The manual control feature (located on the right side of the control panel) consisted of 24 toggle switches (H, V and M) and four 5-position (off, 1, 2, 3, 4) rotary switches (D). These switches individually controlled the 24 indicator lights and the four LED digital displays of the display unit. The physical arrangement of the switches on the control panel corresponded to the arrangement of lights on the display unit; such that, each switch controlled the light in its corresponding position. (The manual switch numbers on the control panel corresponded to the light numbers on the display unit). The manual control feature was used to select any one light, or combination of lights, for display to the subject. Then, provided the applicable submaster switches were "on", the selected lights would be illuminated in the display unit when the stimulus switch was closed. For example, if manual switch V_2, the vertical submaster switch, and the stimulus switch

were in the "on" position, light V_2 would be illuminated on the display unit.

The preselect feature consisted of four, 12-position, rotary, preselect switches (P_1, P_2, P_3, P_4) and a 5-position (off, 1, 2, 3, 4), rotary, preselect control switch (PC). These switches were located on the lower left portion of the control panel. The preselect control switch determined which one, if any, of the four preselect switches was operational. Each position of the preselect switches was preprogrammed to select a combination of ten lights which could be presented, all or in part, on the display unit (dependent on the position of the submaster switches). A combination of the following lights was selected for each of the 48 preselect positions: a green light in the vertical row, a green light in the horizontal row; four red matrix lights (such that, one light was on in each row and one light was on in each column), and a permutation of the digits "1", "2", "3", and "4" in the four LED digital displays. The preselect function, when used in conjunction with the submaster switches, provided the capability of changing the stimulus display of several choice reaction tasks in a random, but efficient manner.

The 5-position, correct response switch (CR), located at the top center of the control panel, selected the CRT task whose correct response would be displayed by the correct response lights (C_1, C_2, C_3, C_4). The CR switch selected one of the following:

1. off
2. 2-stage, 2-bit CRT
3. 3-stage, 2-bit CRT
4. 2-bit CRT (vertical)

5. 2-bit CRT (horizontal)

The correct response for the selected CRT was indicated by the illuminated correct response light. This feature was available only for the 48 preprogrammed stimulus combinations of the preselect switches. That is, the correct response to a stimulus display obtained by using the manual control switches would not be indicated by the correct response lights.

The correct response lights were located just above the corresponding actual response lights (R_1, R_2, R_3, R_4) on the left side of the control panel. By comparing the illuminated correct response light to the actual response light which illuminated when the subject responded, the experimenter was able to quickly determine if the subject had made an error; and, if so, which one.

Located in the upper left portion of the control unit was a small display of 24 lights (no digits) arranged the same as the lights on the subject's display panel. This feature allowed the experimenter to observe the stimulus display (with the exception of the digits) prior to it being presented to the subject. When the stimulus switch was activated, the stimulus display would shift from the control panel to the subject's panel. This duplicator display was controlled by a display control submaster switch (SM_0) located on the top right portion of the control unit.

Timer

A Hewlett-Packard model 3734A, electronic counter was used to measure the elapsed time between the presentation of the stimulus to the subject and his response. The timer started when the stimulus switch was

activated and stopped when any one of the four response switches was depressed.

Bicycle Ergometer

The bicycle ergometer used was a Jaquet Universal Ergostat. The ergometer load could be varied from 0 to 450 watts in five watt increments through the use of calibrated weights and a friction drum mechanism. Pedaling speeds of 30, 40, 60 and 90 rpm could be maintained by monitoring a rate display which indicated the subject's deviation from the set rpm. The tests were performed with the subject seated with his hands on the handlebars.

Experimental Procedures

Experimental Design

During this study, reaction time was measured on a simple reaction task (SRT) and reaction time and error rate were measured on a three-stage choice reaction task (TSCRT). These tasks were performed during exercise or during control, no-exercise, conditions. Combinations of three pedal forces (12.64, 21.07, and 29.49 pounds) and three pedal rates (30, 60, and 90 rpm) were used with the bicycle ergometer to obtain nine exercise conditions, each differing in the work load required of the subject. (The work load, corresponding to each of the conditions, is presented in Table 1).

Eleven male volunteers (all faculty members or graduate students who participated without pay) were randomly assigned to an eight-man exercise group or a three-man control group. (Specific subject data is contained in Table 2).

Table 1. Work Load of Exercise Conditions (watts)

		Rate (RPM)		
		30	60	90
Force (pounds)	12.64	30	60	90
	21.07	50	100	150
	29.49	70	140	210

Table 2. Subject Data

Subject	Age	Height	Weight
1	23	5'-7"	130
2	29	5'-7"	158
3	31	6'-3"	200
4	32	5'-10"	175
5	24	6'-0"	160
6	30	5'-11"	175
7	26	5'-10"	145
8	30	6'-2"	192
9	27	5'-9"	170
10	29	6'-0"	175
11	36	5'-11"	165

The study was conducted in three phases: the unlearned phase (Phase 1), the training phase (Phase 2), and the fully learned phase (Phase 3). The exercise group completed all three phases; whereas, the control group completed only Phase 1.

During Phase 1, (Table 3: sessions 1-18), each member of the exercise group performed each of the two tasks (SRT and TSCRT) under each of the nine exercise conditions, and each member of the control group performed each of the two tasks nine times without exercising. The SRT and TSCRT were performed in an alternating sequence by both the exercise group and the control group. The exercise treatments were presented to the exercise group in a balanced pseudo-random sequence as detailed in Table 3. To insure that learning was not confounded with specific exercise conditions, the testing sequence was randomized, and each subject started at a different point in the sequence. The following example is presented as an aid in the interpretation of Table 3; during Phase 1 on session 16, subject number 3 performed the TSCRT while exercising with a pedal force of 29.49 pounds and at a rate of 90 rpm.

During the training phase, the exercise group performed the TSCRT six times under no-exercise conditions (Table 3: Sessions 19-24). These training sessions were performed to insure that the subjects were fully learned on the TSCRT prior to beginning Phase 3.

During Phase 3, each member of the exercise group was retested on both the SRT and the TSCRT under each of the nine exercise treatments in the same order as presented in Phase 1 (Table 3: Sessions 25-33 and 36-44). Also, in order to serve as their own control during the fully learned phase, each member of the exercise group performed each of the two tasks

Table 3. Sequence of Presentation of Exercise Conditions

SESSION			SUBJECTS										
PHASE			EXPERIMENTAL GROUP								CONTROL		
1	2	3	1	2	3	4	5	6	7	8	9	10	11
1		25	AX1	BX2	CX1	AY2	BY1	CY2	AZ1	BZ2	NE2	NE1	NE2
2		26	BY2	CY1	AY2	BZ1	CZ2	AZ1	BX2	CX1	NE1	NE2	NE1
3		27	CZ1	AZ2	BZ1	CX2	AX1	BX2	CY1	AY2	NE2	NE1	NE2
4		28	AY2	BY1	CY2	AZ1	BZ2	CZ1	AX2	BX1	NE1	NE2	NE1
5		29	BZ1	CZ2	AZ1	BX2	CX1	AX2	BY1	CY2	NE2	NE1	NE2
6		30	CX2	AX1	BX2	CY1	AY2	BY1	CZ2	AZ1	NE1	NE2	NE1
7		31	AZ1	BZ2	CZ1	AX2	BX1	CX2	AY1	BY2	NE2	NE1	NE2
8		32	BX2	CX1	AX2	BY1	CY2	AY1	BZ2	CZ1	NE1	NE2	NE1
9		33	CY1	AY2	BY1	CZ2	AZ1	BZ2	CX1	AX2	NE2	NE1	NE2
		34	NE2	NE1	NE2	NE1	NE2	NE1	NE2	NE1	-	-	-
		35	NE1	NE2	NE1	NE2	NE1	NE2	NE1	NE2	-	-	-
10		36	AX2	BX1	CX2	AY1	BY2	CY1	AZ2	BZ1	NE1	NE2	NE1
11		37	BY1	CY2	AY1	BZ2	CZ1	AZ2	BX1	CX2	NE2	NE1	NE2
12		38	CZ2	AZ1	BZ2	CX1	AX2	BX1	CY2	AY1	NE1	NE2	NE1
13		39	AY1	BY2	CY1	AZ2	BZ1	CZ2	AX1	BX2	NE2	NE1	NE2
14		40	BZ2	CZ1	AZ2	BX1	CX2	AX1	BY2	CY1	NE1	NE2	NE1
15		41	CX1	AX2	BX1	CY2	AY1	BY2	CZ1	AZ2	NE2	NE1	NE2
16		42	AZ2	BZ1	CZ2	AX1	BX2	CX1	AY2	BY1	NE1	NE2	NE1
17		43	BX1	CX2	AX1	BY2	CY1	AY2	BZ1	CZ2	NE2	NE1	NE2
18		44	CY2	AY1	BY2	CZ1	AZ2	BZ1	CX2	AX1	NE1	NE2	NE1
		45	NE1	NE2	NE1	NE2	NE1	NE2	NE1	NE2			
		46	NE2	NE1	NE2	NE1	NE2	NE1	NE2	NE1			
	19		NE2	NE2	NE2	NE2	NE2	NE2	NE2	NE2			
	20		NE2	NE2	NE2	NE2	NE2	NE2	NE2	NE2			
	21		NE2	NE2	NE2	NE2	NE2	NE2	NE2	NE2			
	22		NE2	NE2	NE2	NE2	NE2	NE2	NE2	NE2			
	23		NE2	NE2	NE2	NE2	NE2	NE2	NE2	NE2			
	24		NE2	NE2	NE2	NE2	NE2	NE2	NE2	NE2			

Code:

Force	Rate	Task
A = 12.64 lbs	X = 30 RPM	1 = SRT
B = 21.07 lbs	Y = 60 RPM	2 = TSCRT
C = 29.49 lbs	Z = 90 RPM	

NE = No Exercise

twice under no-exercise conditions; once for each task at the mid-point of Phase 3 (Table 3: Sessions 34 and 35) and once for each task at end of Phase 3 (Table 3: Sessions 45 and 46).

Equipment Arrangement

The subject's display panel was mounted on a wall, at approximately eye level, 48 inches in front of the subject when seated on the bicycle ergometer (Figure 4). The subjects response switches were mounted on the handle bars of the bicycle ergometer, two on each side, such that the subject could easily rest his index and middle fingers on a switch while his palms rested on the appropriate hand grip. Switches one and two were actived by twitching the middle and index fingers, respectively, of the left hand, and switches three and four were activated by twitching the index and middle fingers, respectively, of the right hand.

During the study, the control unit and electronic timer were located behind and to the left of the subject. The subject was allowed to turn around and observe the timer between sets.

Three-Stage Choice Reaction Task (TSCRT)

The TSCRT required the subject to make three sequential cognitive decisions in order to determine the required motor response. The stimulus display presented to the subject on each trial (a stimulus-response combination) consisted of the following lights: one of the four green vertical lights, four red matrix lights (one per row: one per column), and four digits (a permutation of the digits "1", "2", "3", and "4"). The response procedure of each trial was as follows: (1) visually scan the vertical column to identify the illuminated green light, (2) visually scan across the matrix row corresponding to the previously

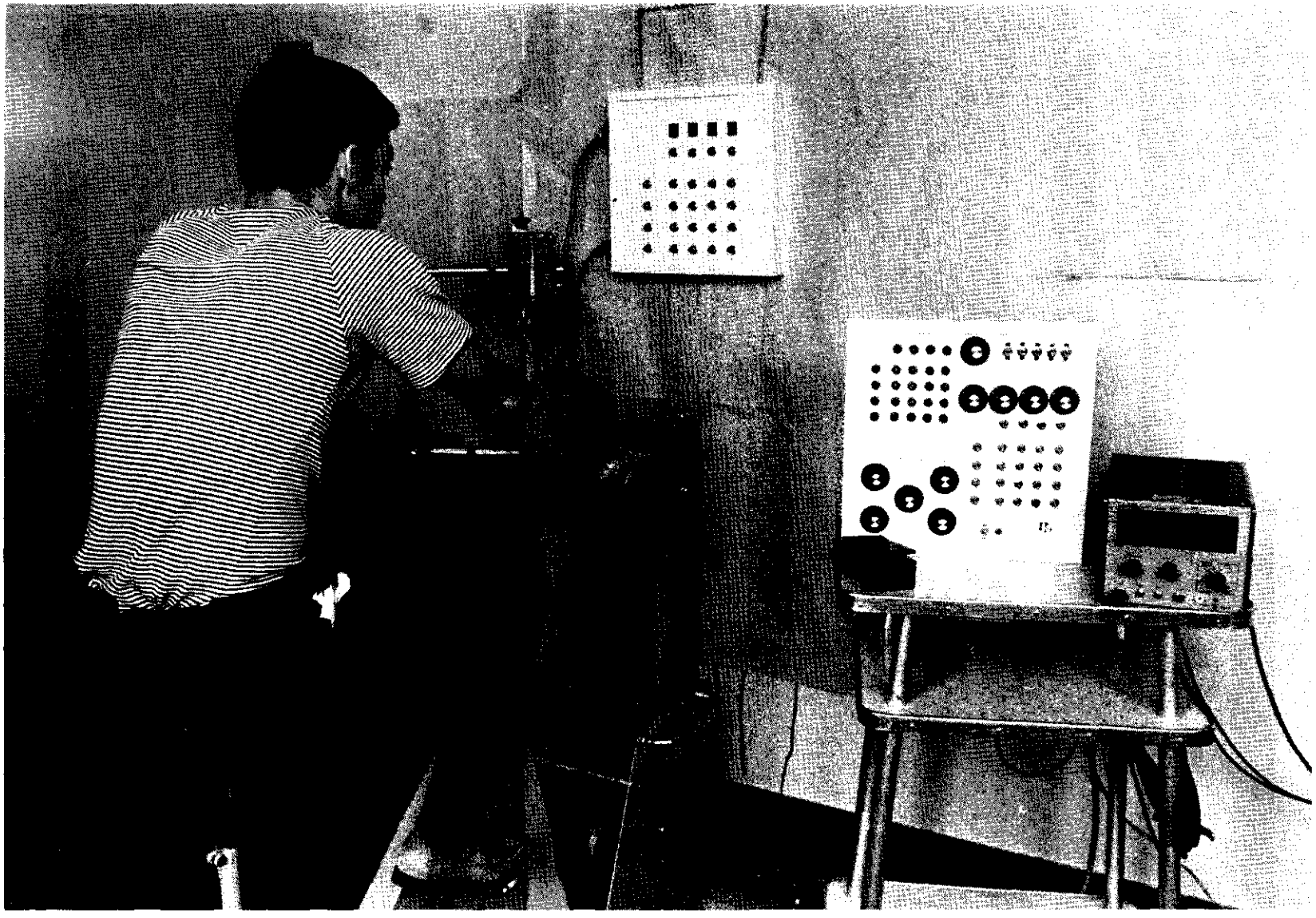


Figure 4. Laboratory Apparatus

identified green vertical light and identify the illuminated red light in that row (3) visually scan up the column of the previously identified red light and read the digit displayed on the indicator in that column (4) physically twitch the applicable finger to depress the response switch corresponding to the previously identified digit. For example (see Figure 2), if light V_2 was illuminated; the subject would read across in the second row of the matrix to the illuminated light, say M_{23}; then he would read up to the digital indicator in the same column (D_3) to obtain the required response, say 4; then he would twitch the middle finger on his right hand to depress response switch 4.

The TSCRT was presented to the subject in sets of 15 trials each, and cumulative response time of the 15 trials was recorded. Also, throughout the set, the actual response light was compared with the correct response light and any errors observed were recorded (e.g., 3/2 would indicate an error when response three was selected instead of response two).

Simple Reaction Task (SRT)

In the SRT the stimulus consisted of the same single light, H_3, which indicated the requirement for the subject to make the standard response of depressing the number three response switch with the forefinger of his right hand. The SRT was presented to the subjects in sets of 20 trials each and the cumulative response time for the 20 trials was recorded.

Testing Procedures

The experimental session was accomplished in accordance with the following format. The subject was briefed on the task and exercise

conditions scheduled for the session. Then, while sitting still on the ergometer, he responded to two sets of stimuli (20 trials per set on the SRT or 15 trials per set on the TSCRT). The sets were presented at one minute intervals. At the start of the third minute of the session, the subject began to exercise on the ergometer at the specified rate and load. Approximately ten seconds after beginning to pedal, the subject was presented with the first stimulus of the third set. A set of stimuli was started at the beginning of each minute thereafter, and the subject continued to exercise between sets. Each session lasted until the subject became fatigued and was unable to continue, or until 20 exercise sets had been completed. Upon completion of the exercise portion, the subject performed two additional sets, at one minute intervals, while remaining seated on the ergometer.

Throughout the session, a set of trials was started at the beginning of a minute and required 35-50 seconds to complete. The subject would continue to exercise (or, for control/no-exercise conditions, sit still) for the 10-25 seconds between sets. Each set was preceded by a "ready" command.

The control group sessions of Phase 1 and the no-exercise sessions of Phases 2 and 3 were conducted exactly the same as the exercise sessions, except that no exercise was performed. The subjects responded to two pre-exercise sets, 20 no-exercise sets, and two recovery sets, presented at one minute intervals, during each session.

Statistical Techniques

For analysis purposes, each experimental session was broken down into six periods. The first period, pre-exercise, consisted of the first two sets, which were conducted prior to exercise. The second period, initial exercise, consisted of set number three which was the first set accomplished while exercising. Periods three, four and five were the first third, second third, and third third, respectively, of the exercise portion of the test session. The sixth period, recovery, consisted of the final two sets which were performed while sitting still on the ergometer.

For both the SRT and TSCRT, the average reaction time per stimulus was obtained for each period. For the TSCRT, the average error rate per 15 stimuli was also obtained for each period. The Shannon-Weaver information transmission rate was calculated for each session (not for each period) of Phase 3 for the TSCRT.

The data was analyzed by using the Analysis of Variance and Breakdown subprograms of the Statistical Package for the Social Sciences (SPSS) program on a CDC CYBER-70 computer.

CHAPTER IV

RESULTS

Introduction

This chapter presents the statistical analysis of the data collected during this study.

Data

The raw data for each session was averaged by period to obtain a mean "reaction time per stimulus" value for both the SRT and the TSCRT and a mean "error rate per 15 stimuli" value for each period of the TSCRT. The period means are presented by subject in Appendix A. The average information transmission rate in bits per second was calculated for the entire session (was not broken down by periods) for each TSCRT session in Phase 3 and the last session in Phase 2.

Models

Three ANOVA models were used to analyze the data of Appendix A. Each model used a subset of the total data available. These three models are detailed below.

Model I -- General Exercise Model

This model was designed to analyze the performance of the exercise group of subjects during the various exercise conditions. The data from the exercise sessions of Phases 1 and 3 were used in this analysis. The following reaction time and error rate models were evaluated.

For both the SRT and the TSCRT;

$$RT = u + S_i + P_j + L_k + F_l + R_m + \text{interactions} + e_{n(ijklm)}$$

And for the TSCRT only;

$$ER = u = S_i + P_j + L_k + F_l + R_m + \text{interactions} + e_{n(ijklm)}$$

where RT = reaction time per stimulus

ER = error rate (errors per 15 stimuli)

u = general mean

S_i = subject (i = 8)

P_j = period of test session (j = 1, pre-exercise; 2, initial exercise; 3, 1st third of exercise; 4, 2nd third of exercise; 5; 3rd third of exercise; 6, recovery)

L_k = learning stage (k = 1, sessions 1-6; 2, sessions 7-12; 3, sessions 13-18; 4, sessions 25-33 and 36-44)

F_l = force (l = 1, 12.64 lbs; 2, 21.07 lbs.; 3, 29.49 lbs.)

R_m = rate (m = 1, 30 rpm; 2, 60 rpm; 3, 90 rpm)

e = residual

The ANOVA table for Model I is presented in Table 4.

Model II -- The Effect of Exercise on Learning

This model was designed to compare the performance of the exercise group of subjects during Phase 1 with the performance of the control group during the same phase. The following reaction time and error rate models were evaluated.

Table 4. Model I -- General Exercise Model -- ANOVA of SRT and TSCRT - RT/ER as a Function of Subject, Period, Learning, Force, and Rate

Model: $RT/ER = u + S_i + P_j + L_k + F_l + R_m + \text{interactions} + e_{n(ijklm)}$

Source of Variation	Degrees of Freedom	SRT Reaction Time F	TSCRT Reaction Time F	TSCRT Error Rate F
Subject (S)	7	220.481 **	651.973 **	28.563 **
Period (P)	5	32.215 **	27.886 **	7.362 **
Learning (L)	3	241.134 **	1512.675 **	.289
Force (F)	2	2.619	15.829 **	1.489
Rate (R)	2	44.810 **	2.589	14.398 **
SP	35	2.496 **	1.284	1.229
SL	21	76.663 **	13.469 **	3.258 **
SF	14	4.462 **	10.131 **	1.430
SR	14	2.279 **	3.428 **	1.288
PL	15	10.453 **	8.692 **	1.911 *
PF	10	1.782	1.797	1.497
PR	10	1.222	.543	1.675
LF	6	3.412 **	18.527 **	1.239
LR	6	4.137 **	18.875 **	3.590 *
FR	4	1.761	5.573	1.218
Residual	709			
General Mean		.2249	.9308	.5940
Residual Mean Square		.000392	.00208	.2329

** = Significant at 1% Level
* = Significant at 5% Level

For both the SRT and the TSCRT;

$$RT = u + C_i + P_j + L_k + \text{interactions} + e_{l(ijk)}$$

And for the TSCRT only;

$$ER = u + C_i + P_j + L_k + \text{interactions} + e_{i(ijk)}$$

where RT = reaction time per stimulus

ER = error rate (errors per 15 stimuli)

C_i = control (i = 1, exercise group; 2, control group)

P_j = period of test session (j = same as Model I)

L_k = learning stage (k = 1, sessions 1-6; 2, sessions 7-12; 3, sessions 12-18)

e = residual

The ANOVA table for Model II is presented in Table 5.

Model III -- The Effect of Exercise on Performance of Learned Subjects

This model was designed to compare the performance of the exercise group of subjects during exercise with their performance without exercise. This amounts to a comparison of Phase 3 exercise performance with Phase 3 no-exercise performance. The reaction time, error rate and information transmission rate models evaluated were:

For both the SRT and TSCRT;

$$RT = u + E_i + S_j + L_k + P_l + \text{interactions} + e_{m(ijkl)}$$

Table 5. Model II -- Effects of Exercise on Learning -- ANOVA of SRT and TSCRT - RT/ER as a Function of Control, Period, and Learning

Model: $RT/ER = u + C_i + P_j + L_k + \text{interactions} + e_{l(ijk)}$

Source of Variation	Degrees of Freedom	SRT Reaction Time F	TSCRT Reaction Time F	TSCRT Error Rate F
Control (C)	1	16.697 **	8.197 **	2.003
Period (P)	5	33.007 **	108.444 **	1.897
Learning(L)	2	3.101 **	4.162 **	.282
CP	5	1.417	.392	1.746
CL	2	11.168 **	.083	.347
PL	10	1.128	.844	1.309
Residual	568			
General Mean		.2257	1.0273	.5820
Resdiual Mean Square		.00301	.01956	.3413

** = Significant at 1% Level
* = Significant at 5% Level

And for the TSCRT only;

$$ER = u + E_i + S_j + L_k + P_l + \text{interactions} + e_{m(ijkl)}$$

$$HT = u + E_i + S_j + L_k + \text{interactions} + e_{l(ijk)}$$

Where RT = reaction time per stimulus

ER = error rate (errors per 15 stimuli)

HT = information transmission rate (bits per sec)

E_i = exercise condition (i = 1, exercise; 2, no-exercise)

S_j = subject effect, (j = 8)

L_k = learning stage, (k = 4, sessions 24-30; 5, sessions 31-38; 6, sessions 39-46)

P_l = period of test session (1 = same as j of Model I)

e = residual

The RT and ER analysis of Model III is presented in Table 6, and the HT analysis is presented in Table 7.

Statistical Assumptions of ANOVA Models

Breakdown of Sessions into Periods

The fact that the individual test sessions were broken down into six periods and the ANOVA conducted on the period means created two statistical problems.

First; the period means were based on a different number of data points. For example, on the TSCRT, periods 1 and 6 always contained 2 sets or a total of 30 stimulus-response trials; period 2 always contained

Table 6. Model III -- Effects of Exercise on Performance -- ANOVA of SRT and TSCRT - RT/ER as a Function of Subject, Exercise, Learning and Period

Model: $RT/ER = u + S_i + E_j + L_k + P_l + \text{interactions} + e_{m(ijkl)}$

Source of Variation	Degrees of Freedom	SRT Reaction Time F	TSCRT Reaction Time F	TSCRT Error Rate F
Subject (S)	7	157.295 **	1302.216 **	19.472 **
Exercise(E)	1	1.835	3.815 *	6.671 **
Learning(L)	2	16.849 **	195.681 **	.067
Period (P)	5	16.924 **	22.979 **	4.301 **
SE	7	5.966 **	2.679 **	.695
SL	14	5.971 **	7.186 **	2.642 **
SP	35	2.721 **	1.125	1.453 *
EL	2	4.721 *	1.036	.853
EP	5	1.103	2.528 *	1.485
LP	10	.750	.667	.702
Residual	575			
General Mean		.2185	.8455	.5589
Residual Mean Square		.000139	.000562	.1806

** = Significant at 1% Level
* = Significant at 5% Level

Table 7. Model III -- The Effect of Exercise on Performance -- ANOVA of TSCRT -- Information Transmission Rate as a Function of Subject, Exercise, and Learning

Model: $HT = u + S_i + E_j + L_k + \text{interactions} + e_{1(ijk)}$

Source of Variation	Degrees of Freedom	TSCRT Info Rate F
Subject (S)	7	80.960 **
Exercise(E)	1	1.085
Learning(L)	2	27.737 **
SE	7	.478
SL	14	2.016 *
EL	2	1.382
Residual	95	
General Mean		2.1140
Residual Mean Square		.00359

** = Significant at 1% Level
* = Significant at 5% Level

1 set of 15 trials; while periods 3, 4, and 5 normally contained 7, 6, and 6 sets or a total of 105, 90, and 90 trials, respectively. When the session was curtailed due to fatigue, periods 3, 4, and 5 contained a proportionately smaller number of sets. Thus, there is a large difference in precision of the variance estimates of the individual periods. That is, the period estimates (P_i) were not homoscedastic as assumed for the F-tests in the ANOVA.

The second statistical problem associated with the breakdown of the test sessions into six periods was that the initial exercise period (period 2) and the first-third of exercise period (period 3) were not independent. Period 2 data was also contained within period 3. Period 2 was analyzed separately because it was felt that the initial exercise effect would be significant and it was desired not to hide this effect within the first-third of exercise effect.

Although the breakdown of the test session into periods created the above statistical problems which will affect the F-tests, the errors introduced in the ANOVA may not be of sufficient magnitude to justify statistical manipulations of the data.

Contrasts

Contrasts were not used on the main effects of any of the models since most of this type of information could be obtained from the graphs of Chapter V.

Learning

Although the study was designed to have the subjects fully learned on both the SRT and the TSCRT prior to beginning Phase 3, some residual learning appeared to have occurred on the TSCRT during Phase 3. Therefore,

a learning term was included in Model III in order to determine the significance of any residual learning that occurred during Phase 3.

Subject Term for Model II

The performance data of two groups of subjects, a control group and an exercise group, were used in the analysis of Model II. In the model tested, the subject effect was included within the control effect (C_i). A nested model, in which the subject effect was nested within the control effect, would not have provided the true control effect, because it could not be determined if the control effect was due to the effects of exercise or due to a difference between the average skill level of the control group subjects and the exercise group subjects. The rapid learning associated with Phase 1 prevented the exercise group from serving as their own control. Therefore, the only way to separate the control and subject effects was to have an extremely large number of subjects in both the control group and the exercise group so that it could be assumed that the subjects were drawn from the same population and that control effect was the "true" control effect. Since it was impractical to separate the control effect and the subject effect, it was decided to run the easier, unnested model and to analyze the data primarily through the graphs of Chapter V.

Interactions

Second order and above interactions were not used in any of the three models. These higher order interactions could not be interpreted from a practical point of view, and by pooling them with the residuals, the F-tests of the remaining terms tended to be more conservative. The internal variation, as indicated by the RMS, of Model I was relatively

close to Model III for all three parameters (RT of SRT, RT of TSCRT and ER of TSCRT) (Tables 4, 5 and 6). The RMS was higher on Model II than on Models I or III because the subject effect was included in the residual term of Model II.

Normality of Error Rate

The residuals of the error rate models of the TSCRT were not normally distributed which violated the assumptions underlying the ANOVA. The residuals of the ER have a skewed distribution caused by the lower limit of zero errors. (For example, the ER mean for Model I was .5940 while the range was from zero to 2.67.) The inaccuracies of the F-tests are not considered to be of such a magnitude as to justify a transformation of the data to a form having normally distributed residuals.

Subjects -- Fixed or Random

All factors, including subjects, were assumed to be at fixed levels in the analysis of Models I and III. Although the subjects were selected at random, they were selected from a specific age and occupational group (graduate students and college professors) and not from the general population. In order to extend the findings to a more universal application, the subject factor would have to be treated as random, in which case, the F-values and significant levels of the main effects in ANOVA Tables 4, 6, and 7 would be modified as shown in Table 8.

Table 8. Modification of Tables 4, 6, and 7 when the Subject Levels are Assumed to be Random

Table	Source of Variation	SRT RT F	TSCRT RT F	TSCRT ER F	TSCRT HT F
4	Period	12.917 **	21.829 **	5.990 **	
	Learning	3.146 *	112.357 **	.089	
	Force	.560	1.556	1.042	
	Rate	18.846 **	.77	11.181 **	
6	Exercise	.297	1.273	9.607 **	
	Learning	2.917	27.018 **	.025	
	Period	6.462 **	20.682 **	2.961 **	
7	Exercise				2.333
	Learning				13.774 **

CHAPTER V

DISCUSSION

This chapter discusses the experimental results presented in Chapter IV.

Introduction

The following discussion is aided by a series of graphs (Figures 5-27) on which all the main effects and most of the two-way interactions for all three models of both the SRT and the TSCRT are plotted against reaction time, (RT), error rate (ER) and information transmission rate (HT), if appropriate. Figure 28 contains graphs of the exercise work load in watts plotted against RT, ER, and HT for the fully learned conditions, Phase 3. Frequent reference will be made to these graphs during the subsequent discussion.

Main Effects

Subject Effect

In both the SRT and TSCRT a statistically significant subject effect was detected at the 1% level of significance (Tables 4, 6, and 7). It is believed that this effect resulted from natural subject variability, due in part to the inherent differences in skill, quickness, strategy and/or motivation between subjects.

A comparison of the individual subject's average reaction time (Figure 15A) and average error rate (Figure 15B) on the TSCRT indicated that those subjects with a relatively fast reaction time tended to have

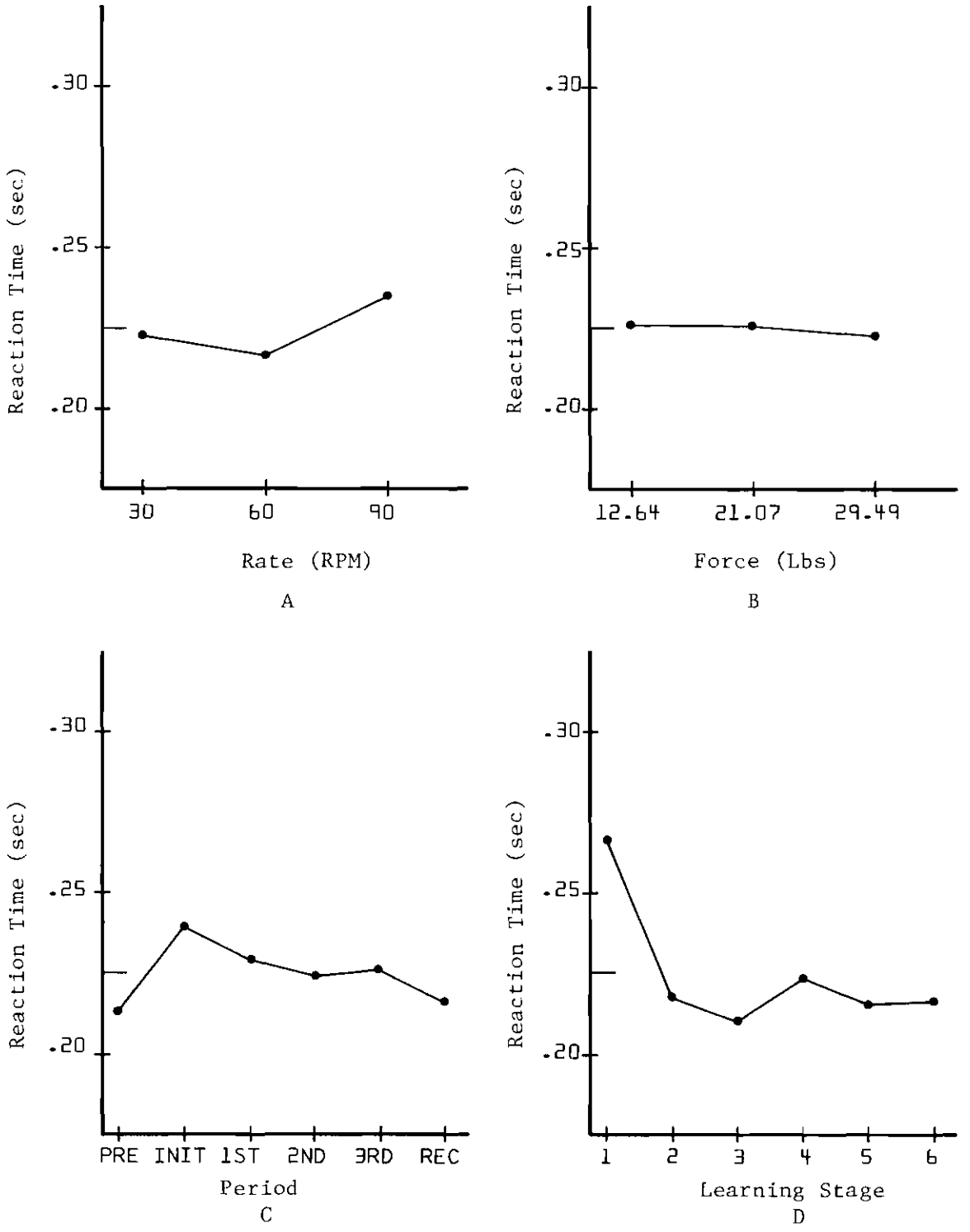


Figure 5. SRT -- Model I -- Main Effect

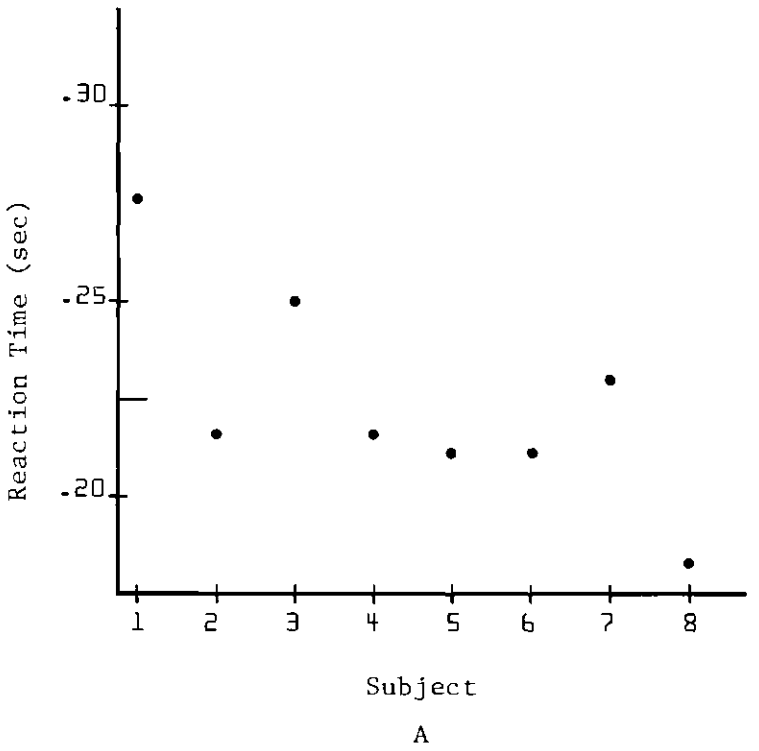


Figure 6. SRT -- Model I -- Main Effects

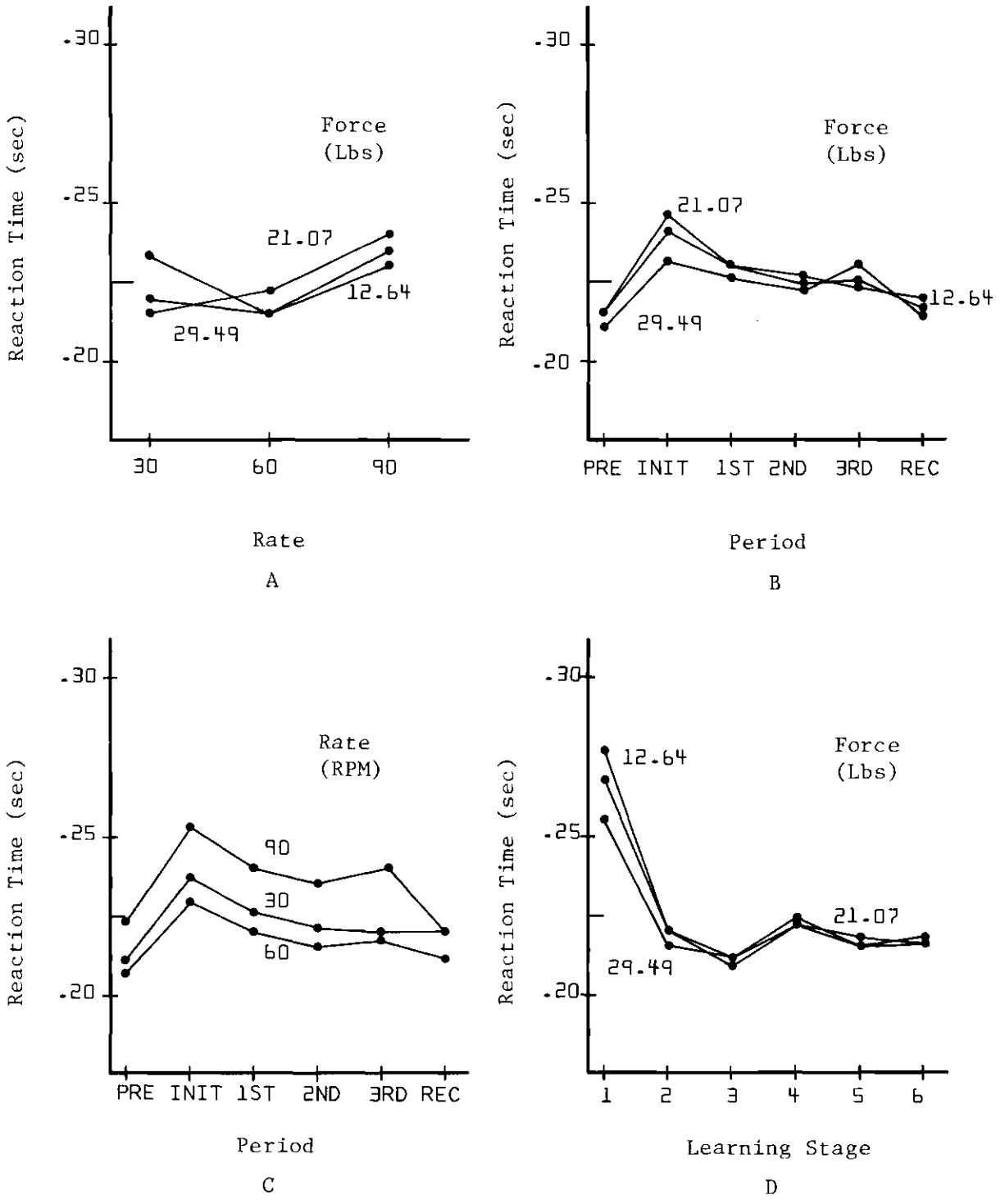


Figure 7. SRT -- Model I -- 1st Order Interactions

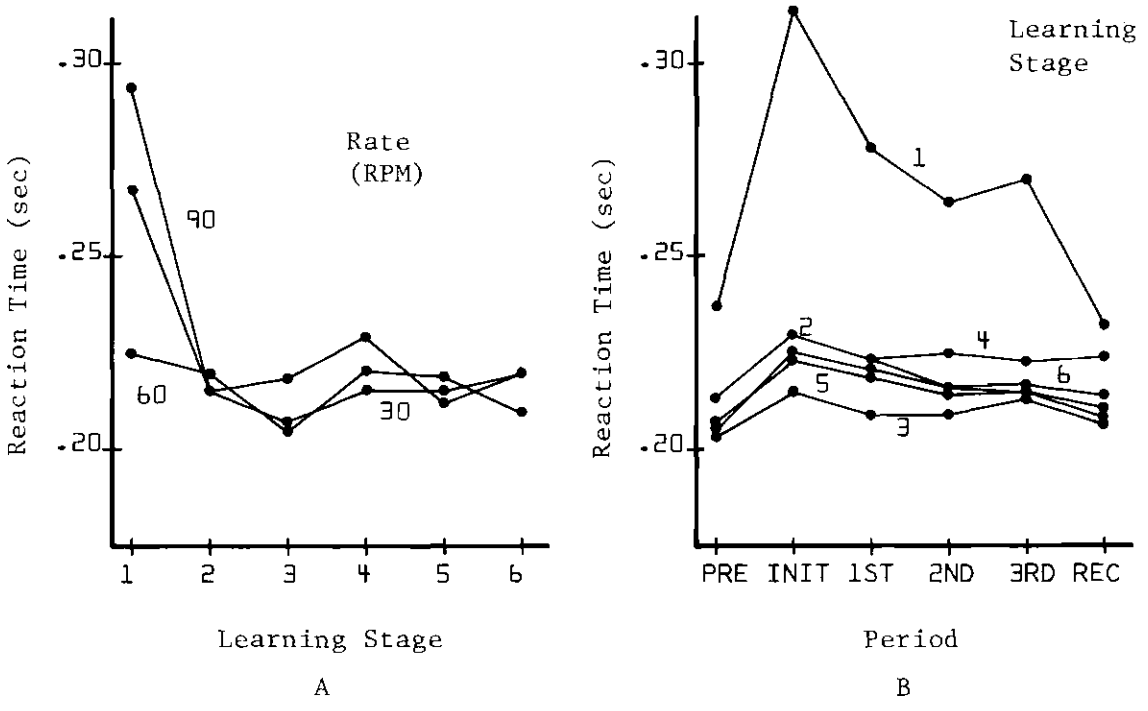


Figure 8. SRT -- Model 1 -- 1st Order Interactions

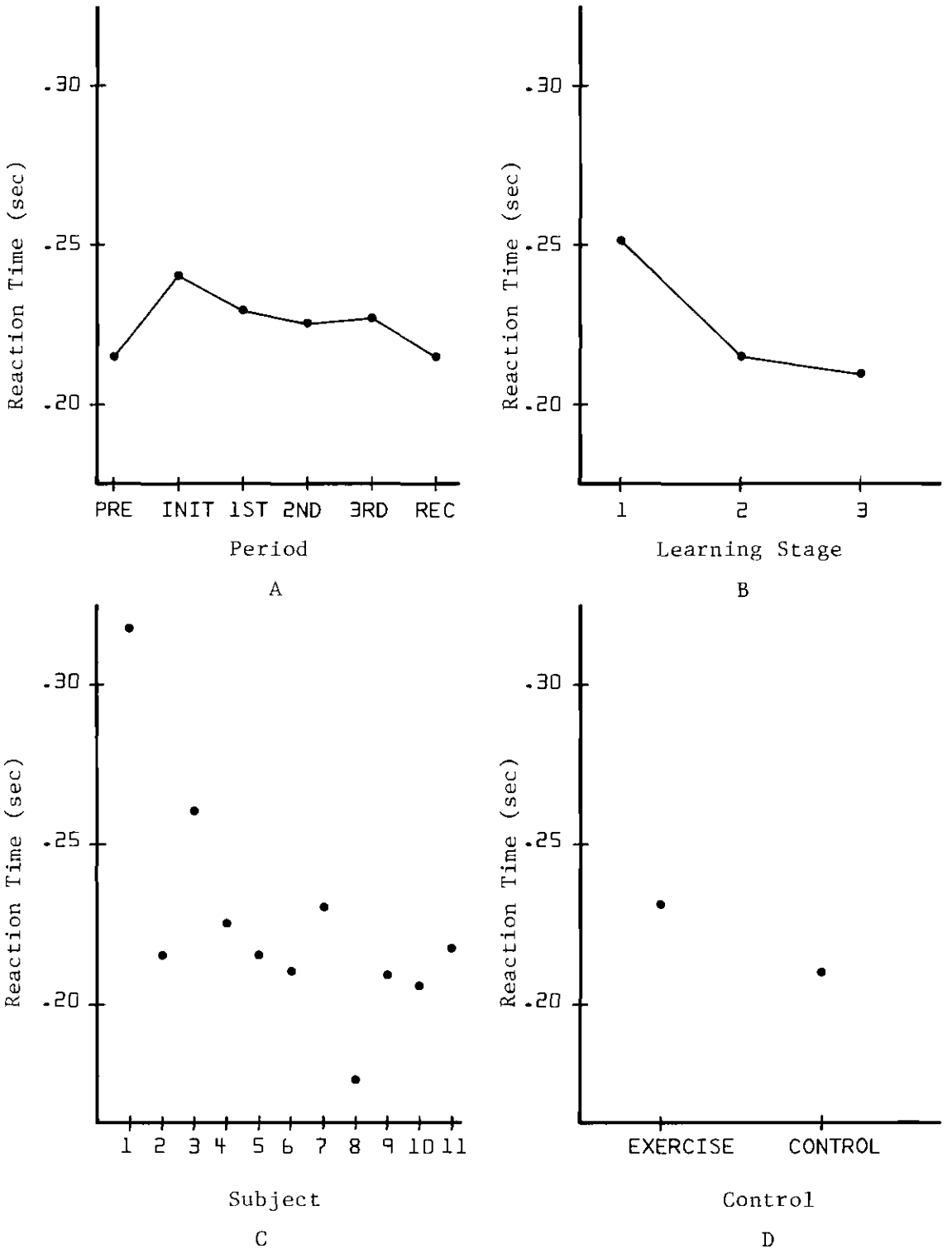


Figure 9. SRT -- Model II -- Main Effects

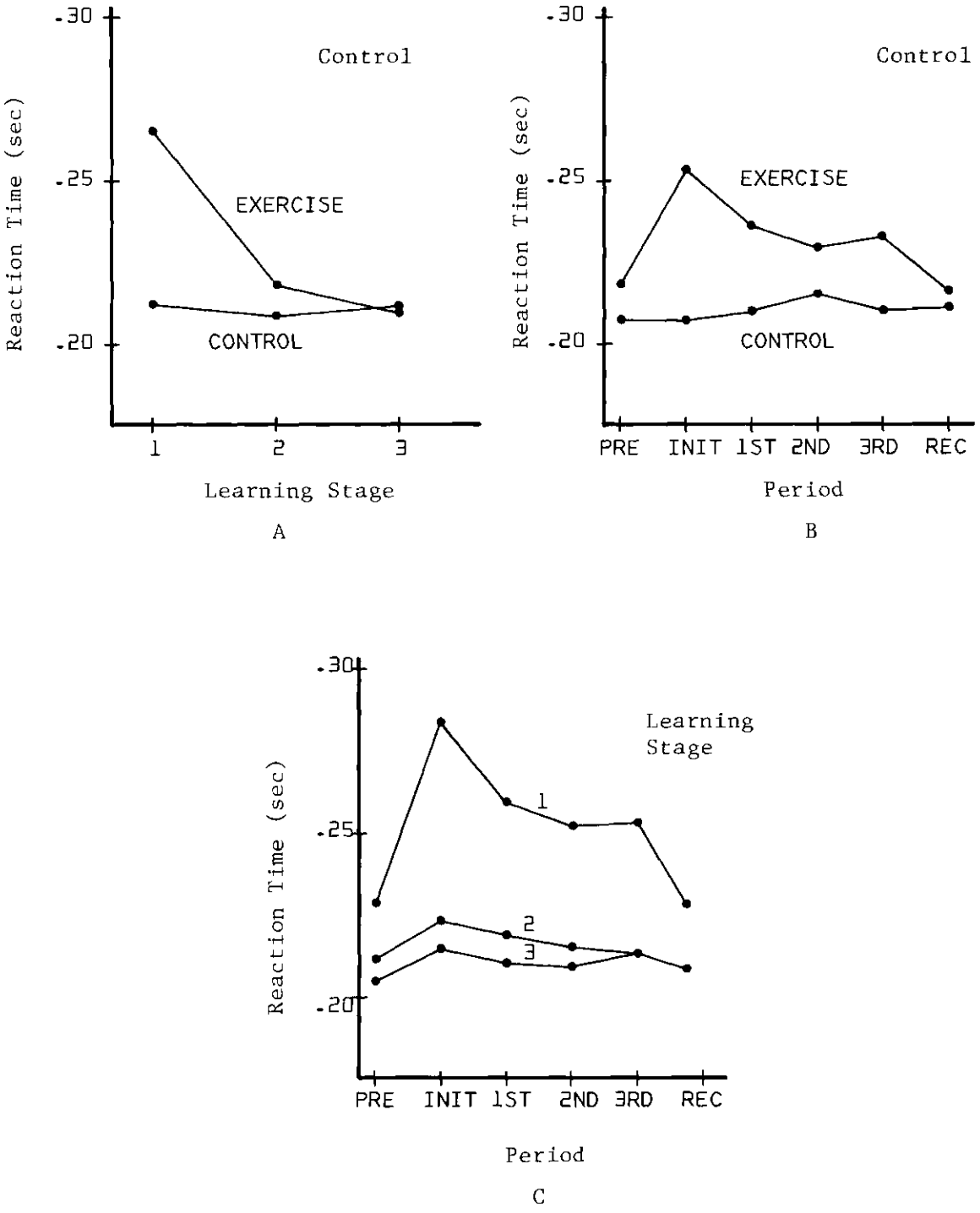


Figure 10. SRT -- Model II -- 1st Order Interactions

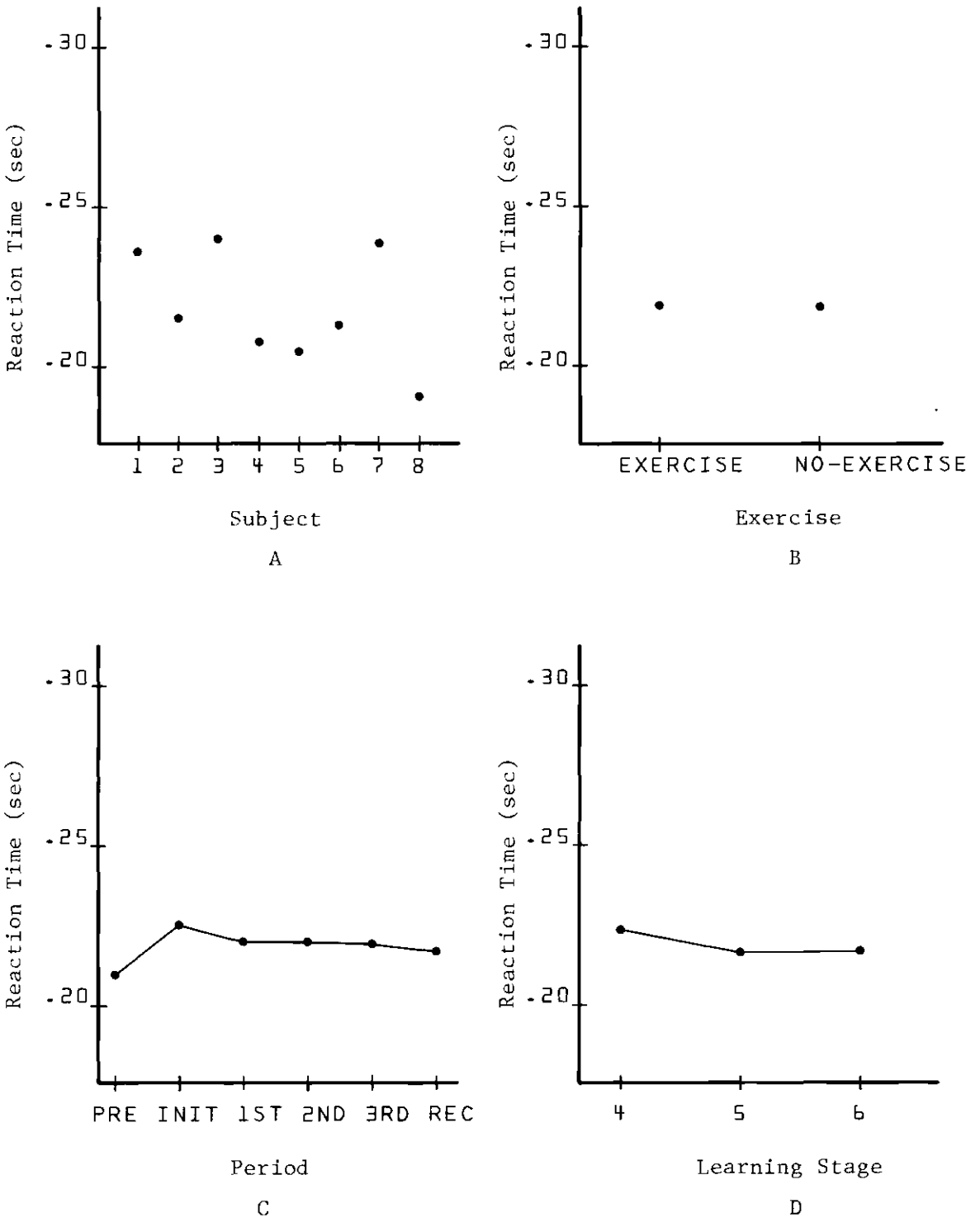


Figure 11. SRT -- Model III -- Main Effects

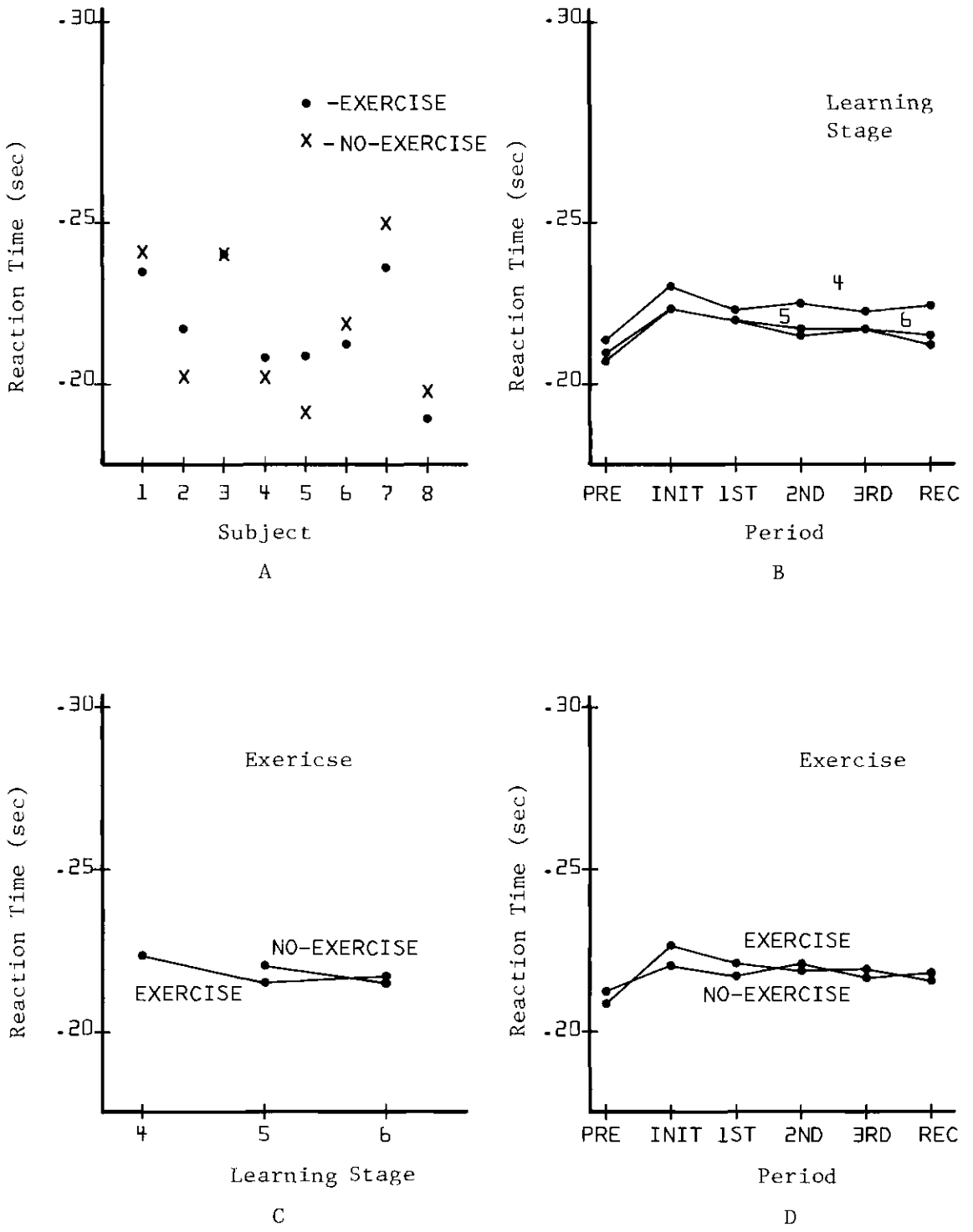


Figure 12. SRT -- Model III -- 1st Order Interactions

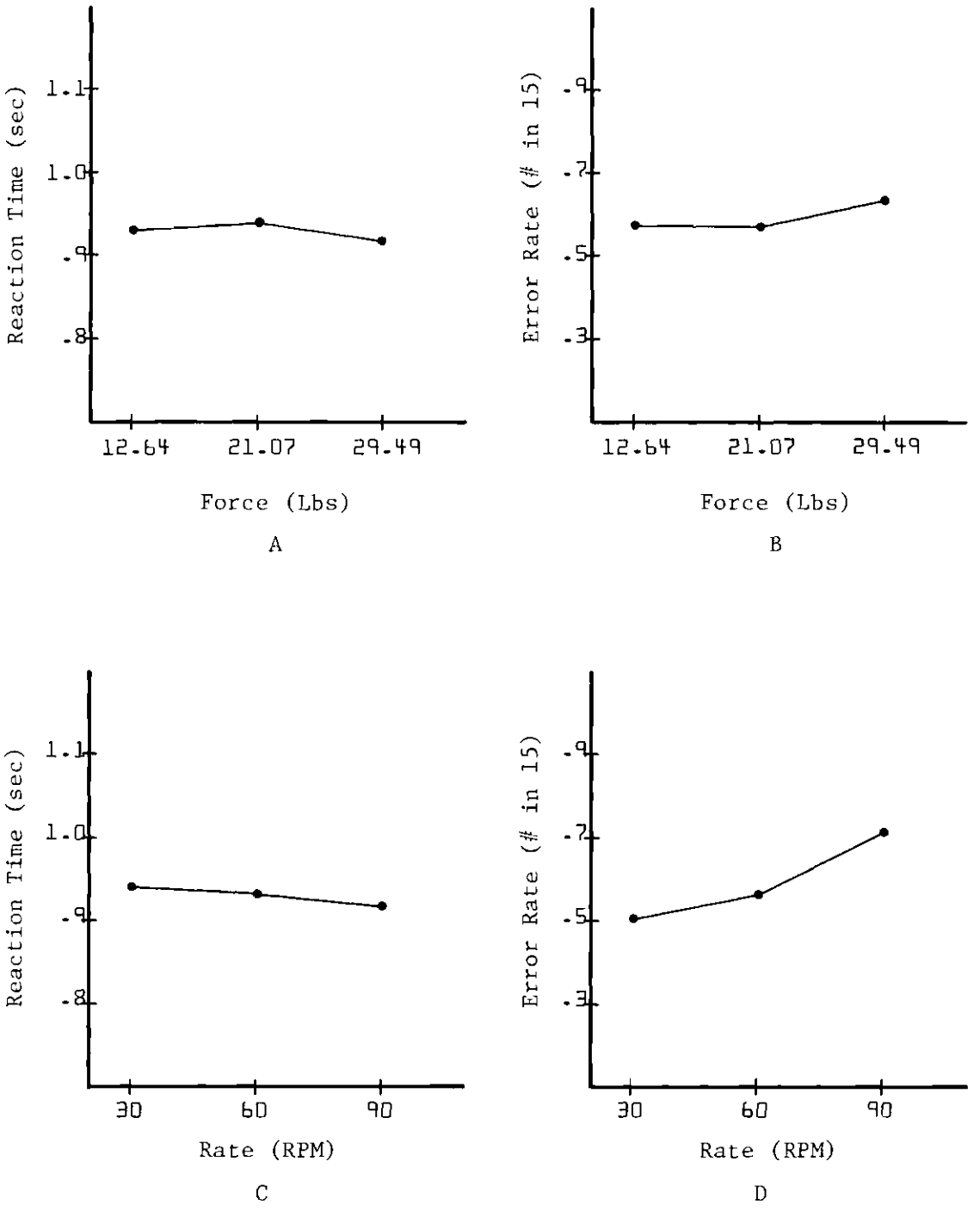


Figure 13. TSCRT -- Model I -- Main Effects

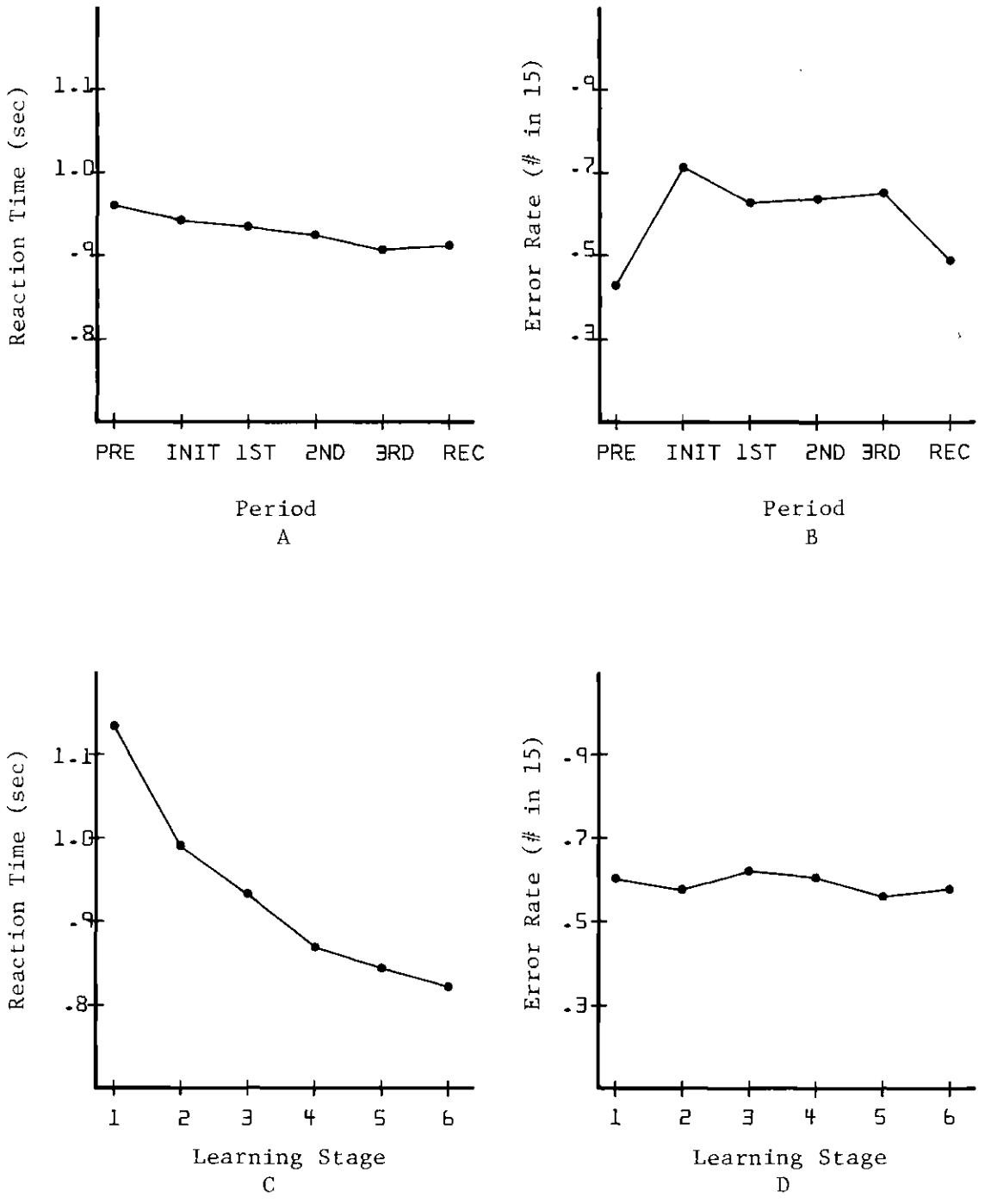


Figure 14. TSCRT -- Model I -- Main Effects

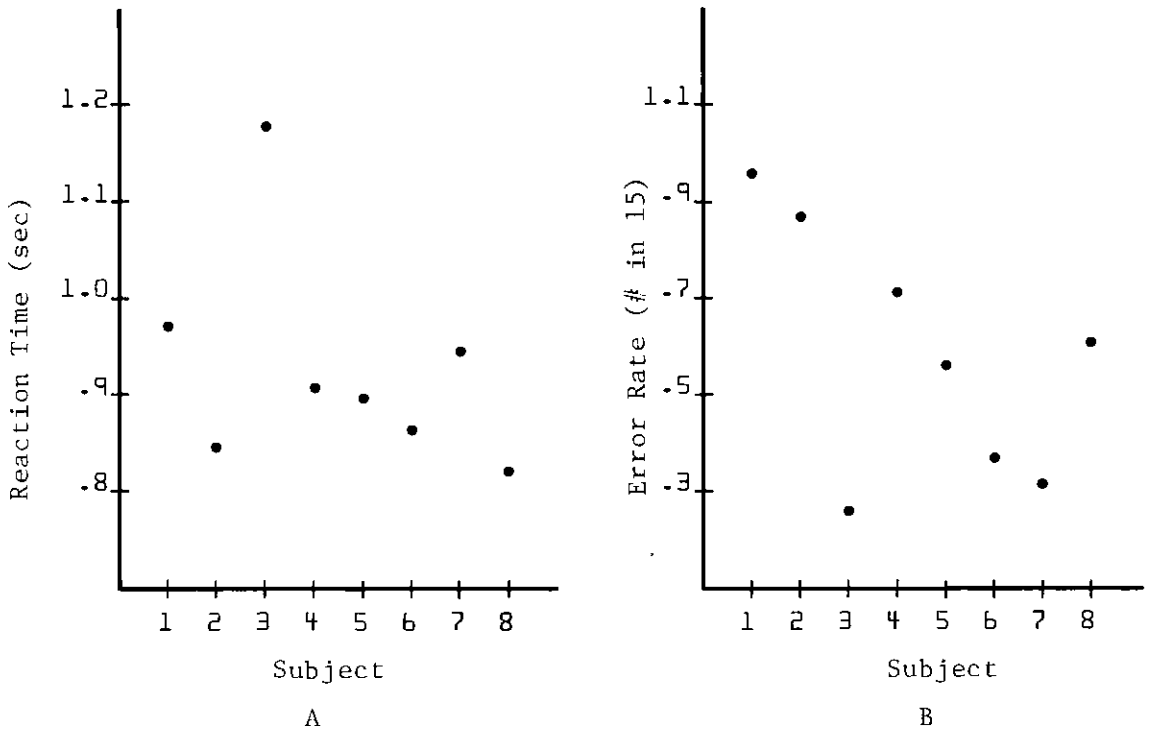


Figure 15. TSCRT -- Model I -- Main Effects

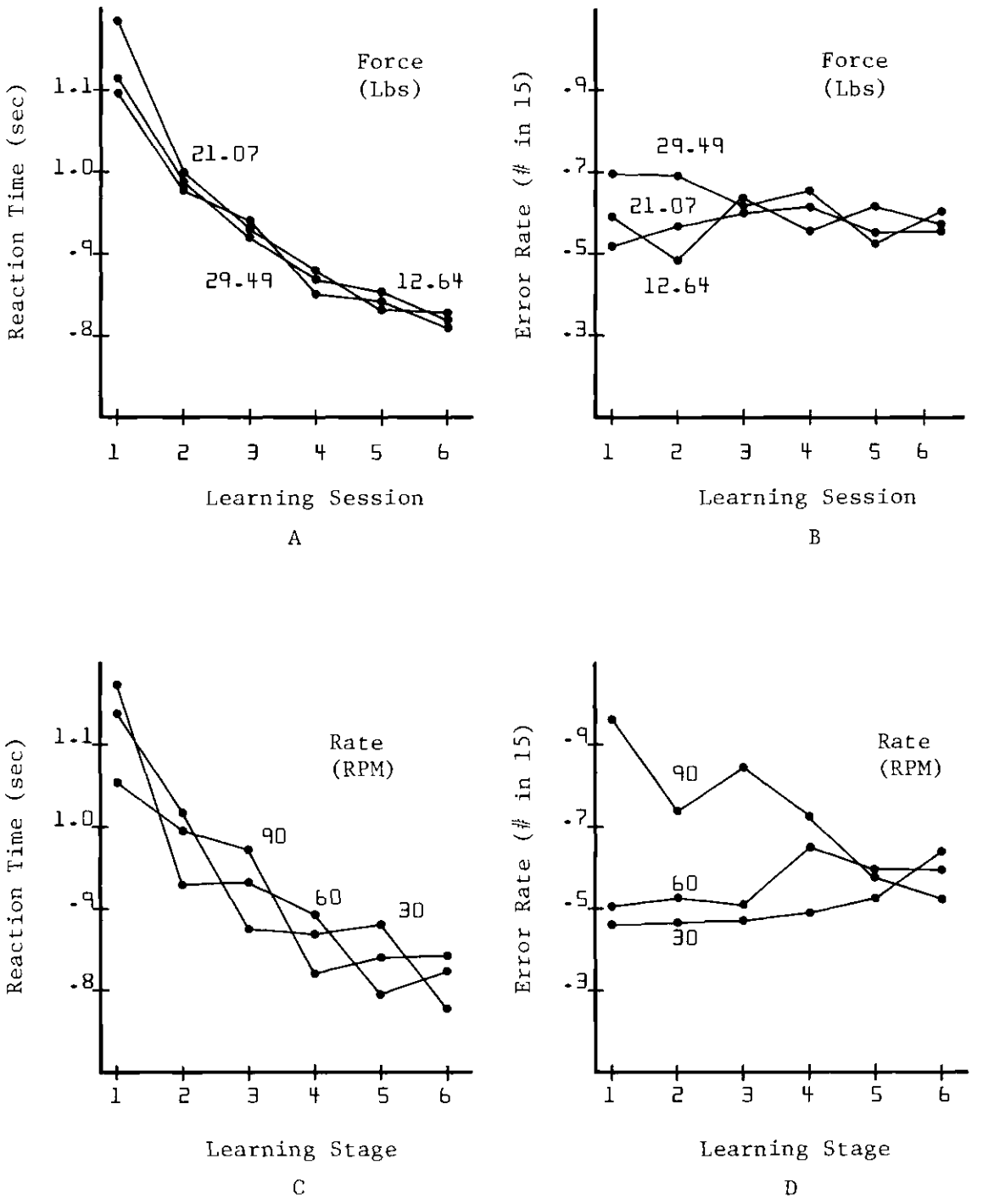


Figure 16. TSCRT -- Model I -- 1st Order Interactions

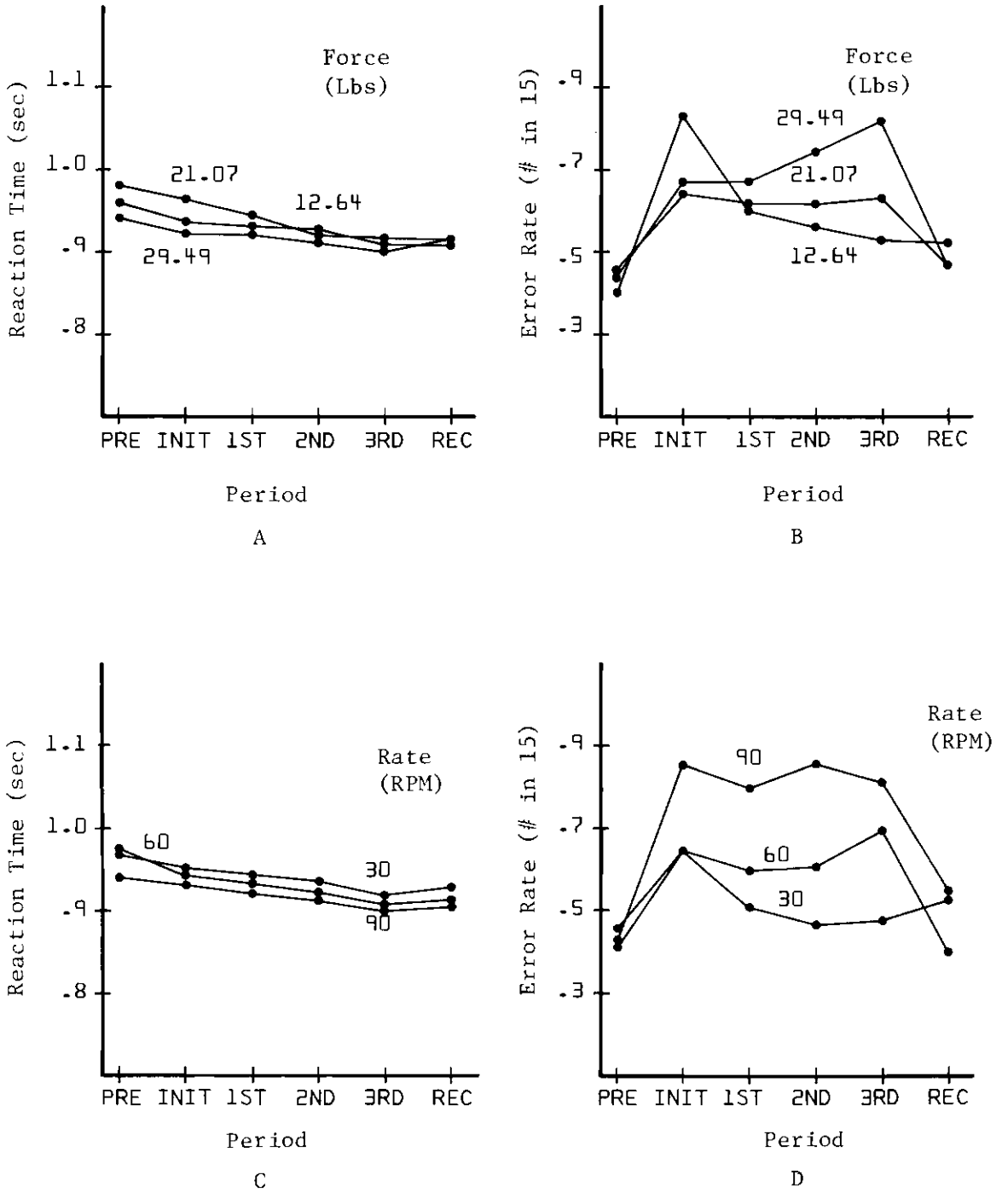


Figure 17. TSCRT -- Model I -- 1st Order Interactions

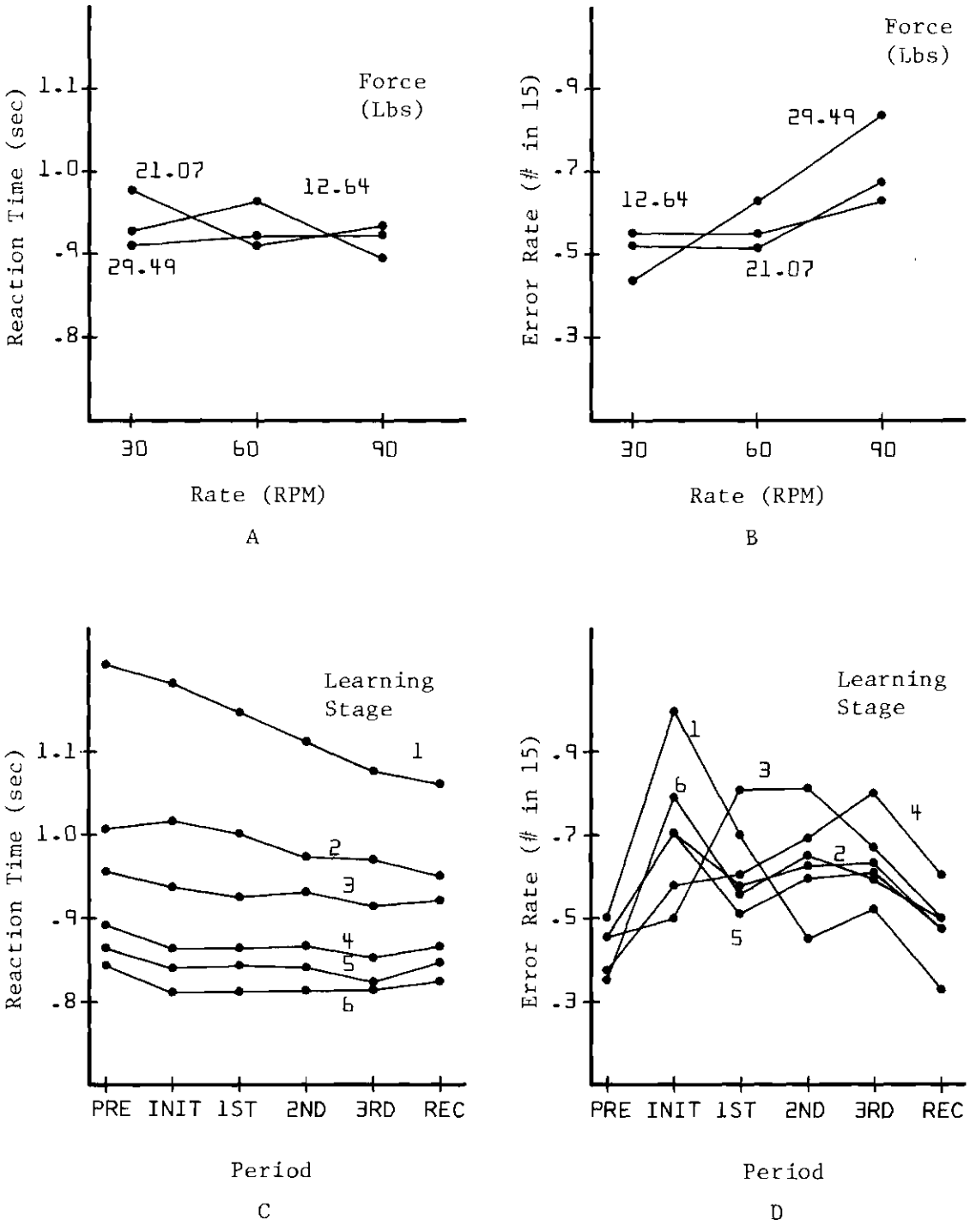


Figure 18. TSCRT -- Model I -- 1st Order Interactions

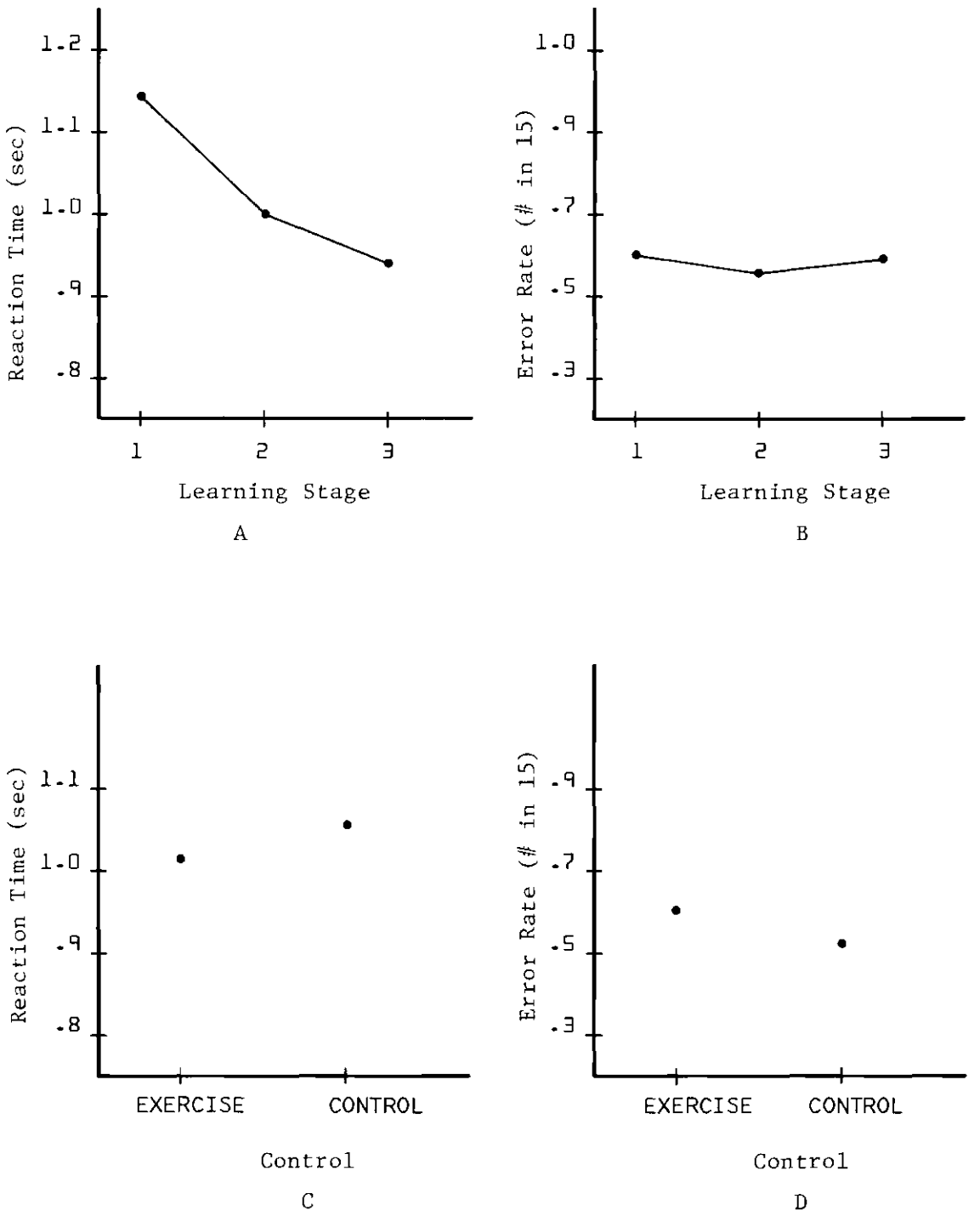


Figure 19. TSCRT -- Model II -- Main Effects

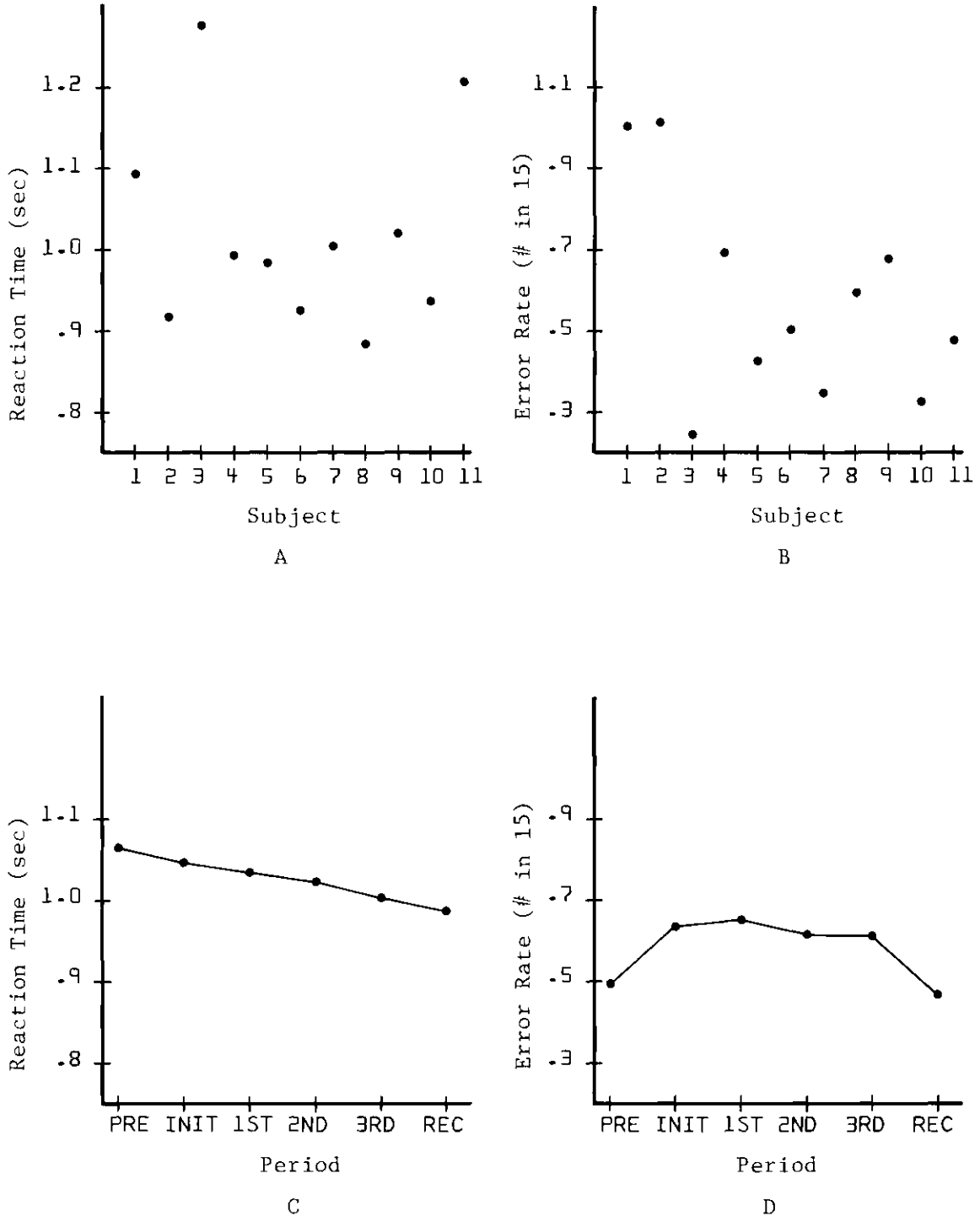


Figure 20. TSCRT -- Model II -- Main Effects

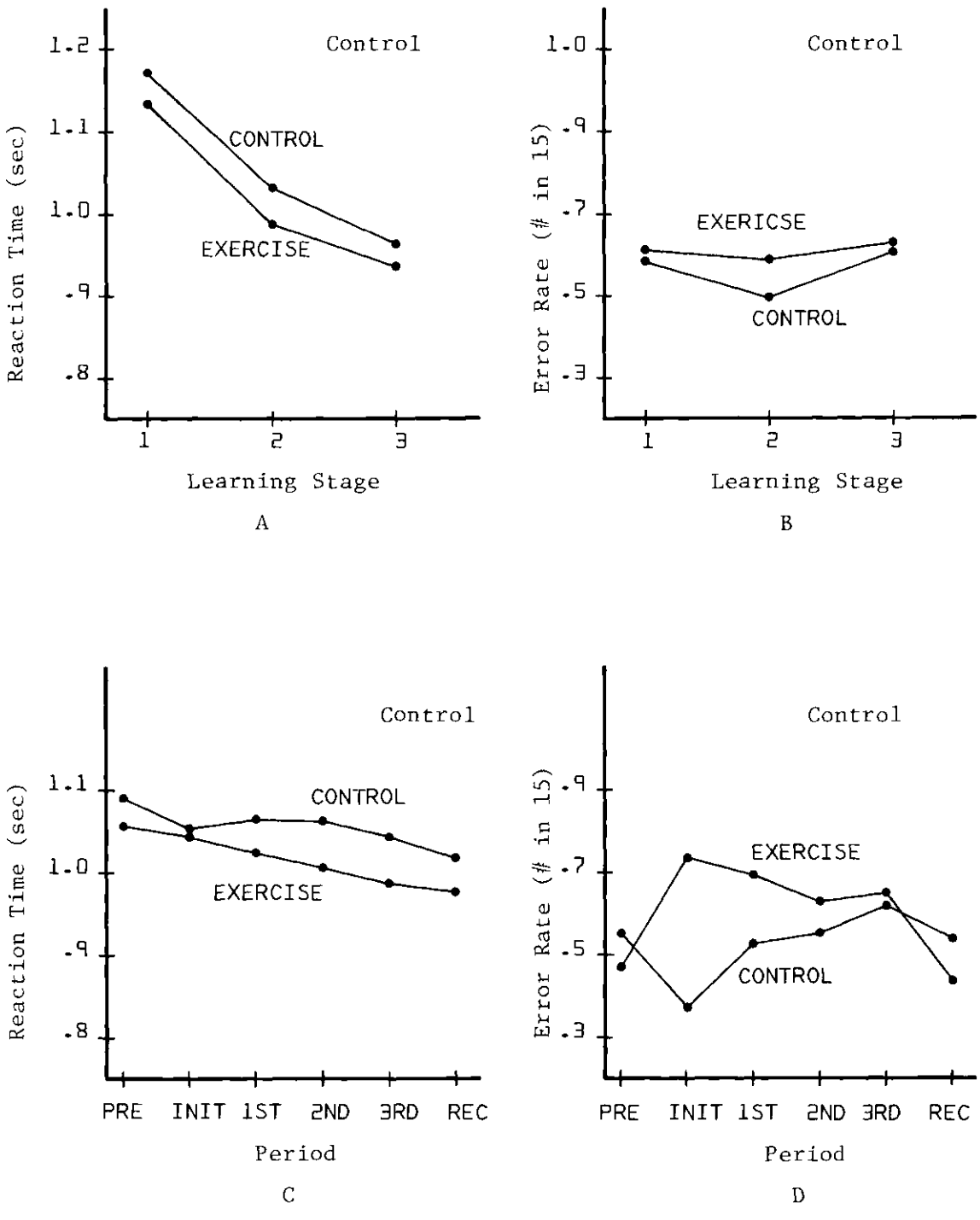


Figure 21. TSCRT -- Model II -- 1st Order Interactions

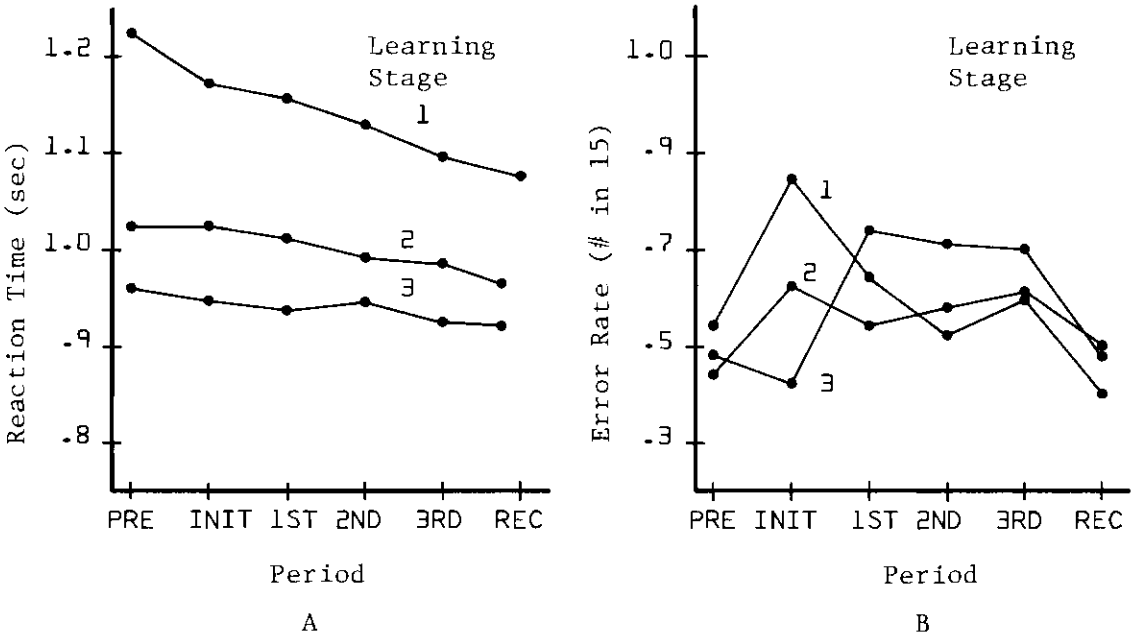


Figure 22. TSCRT -- Model II - 1st Order Interactions

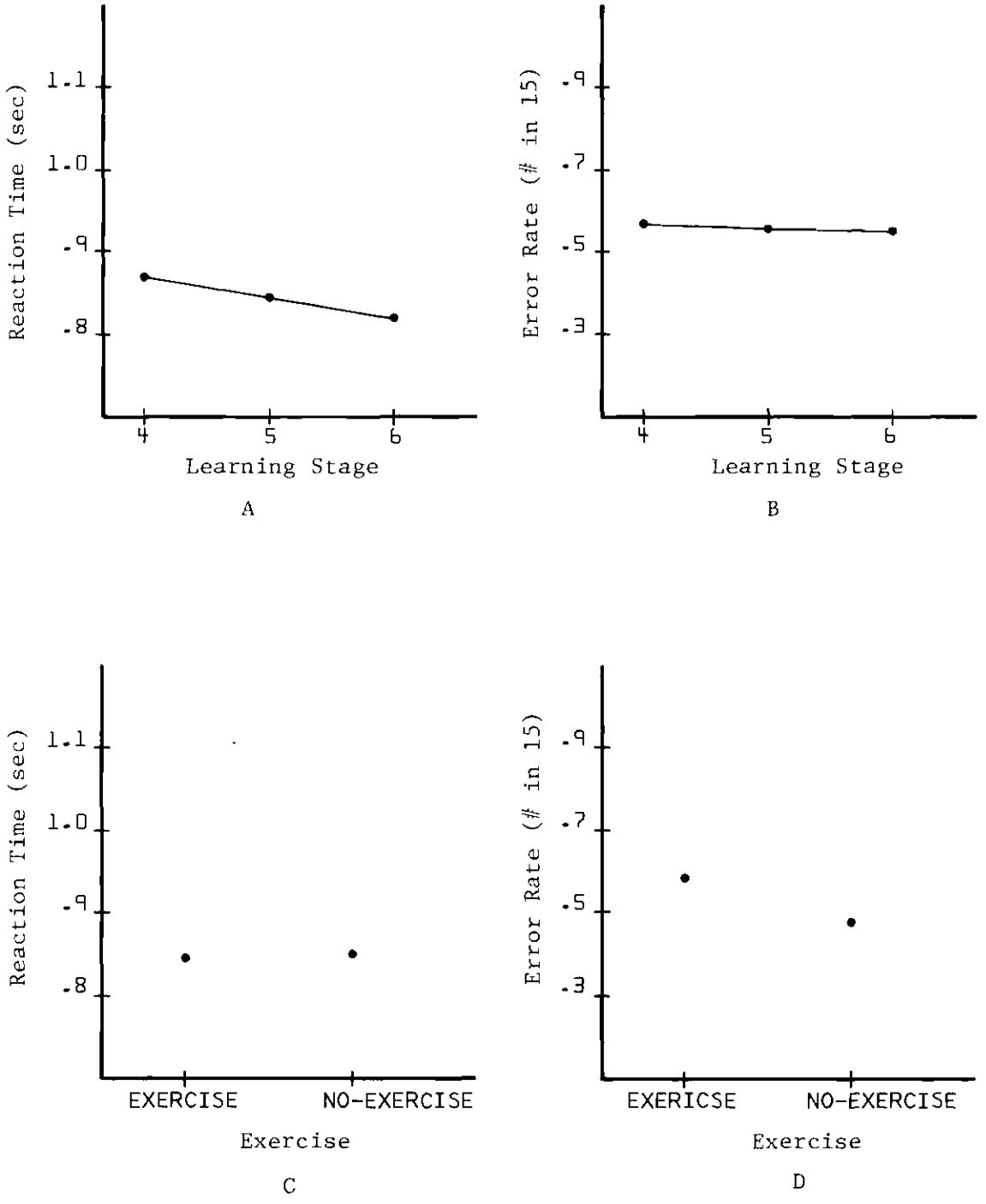


Figure 23. TSCRT -- Model III -- Main Effects

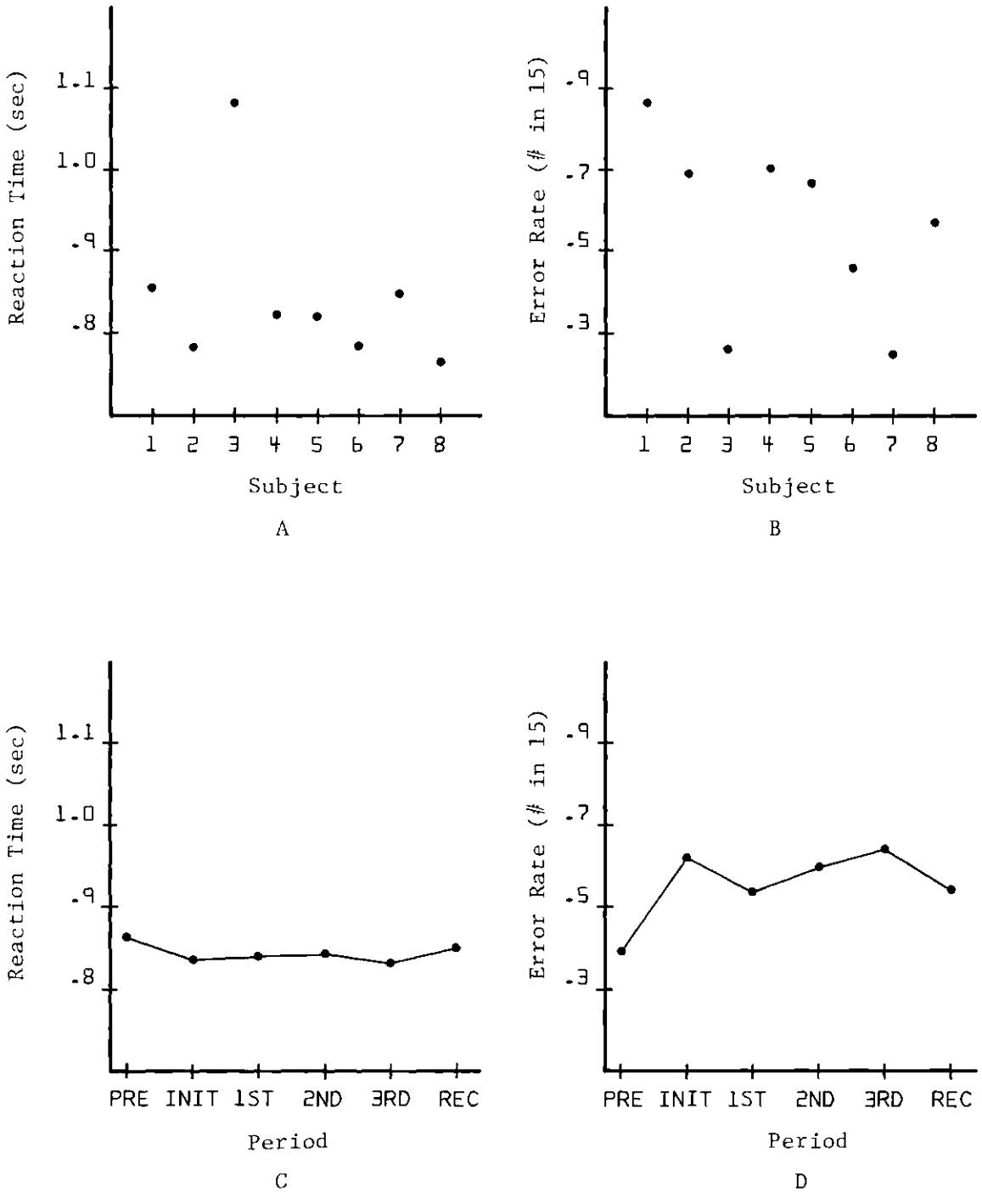


Figure 24. TSCRT -- Model III -- Main Effects

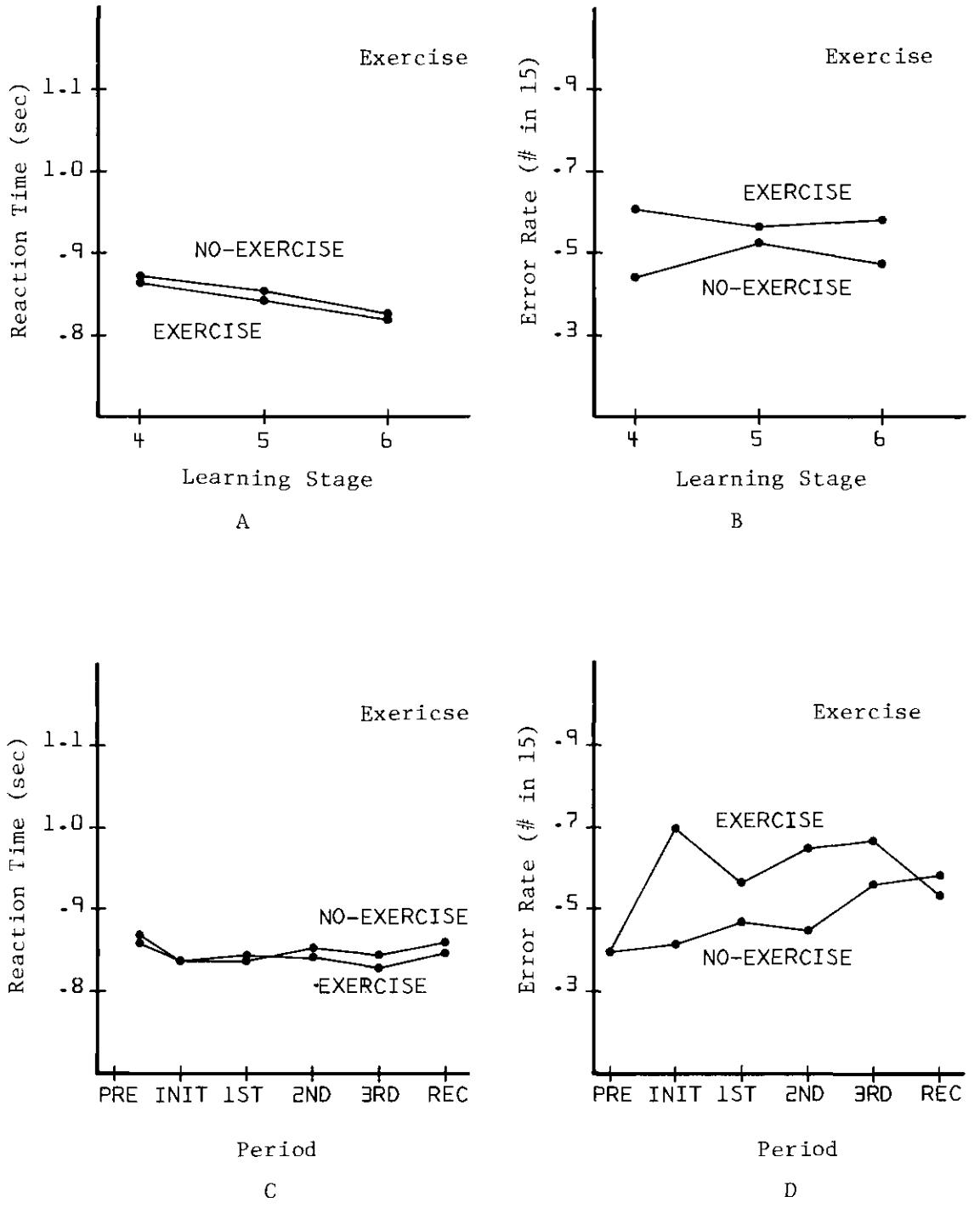


Figure 25. TSCRT -- Model III -- 1st Order Interactions

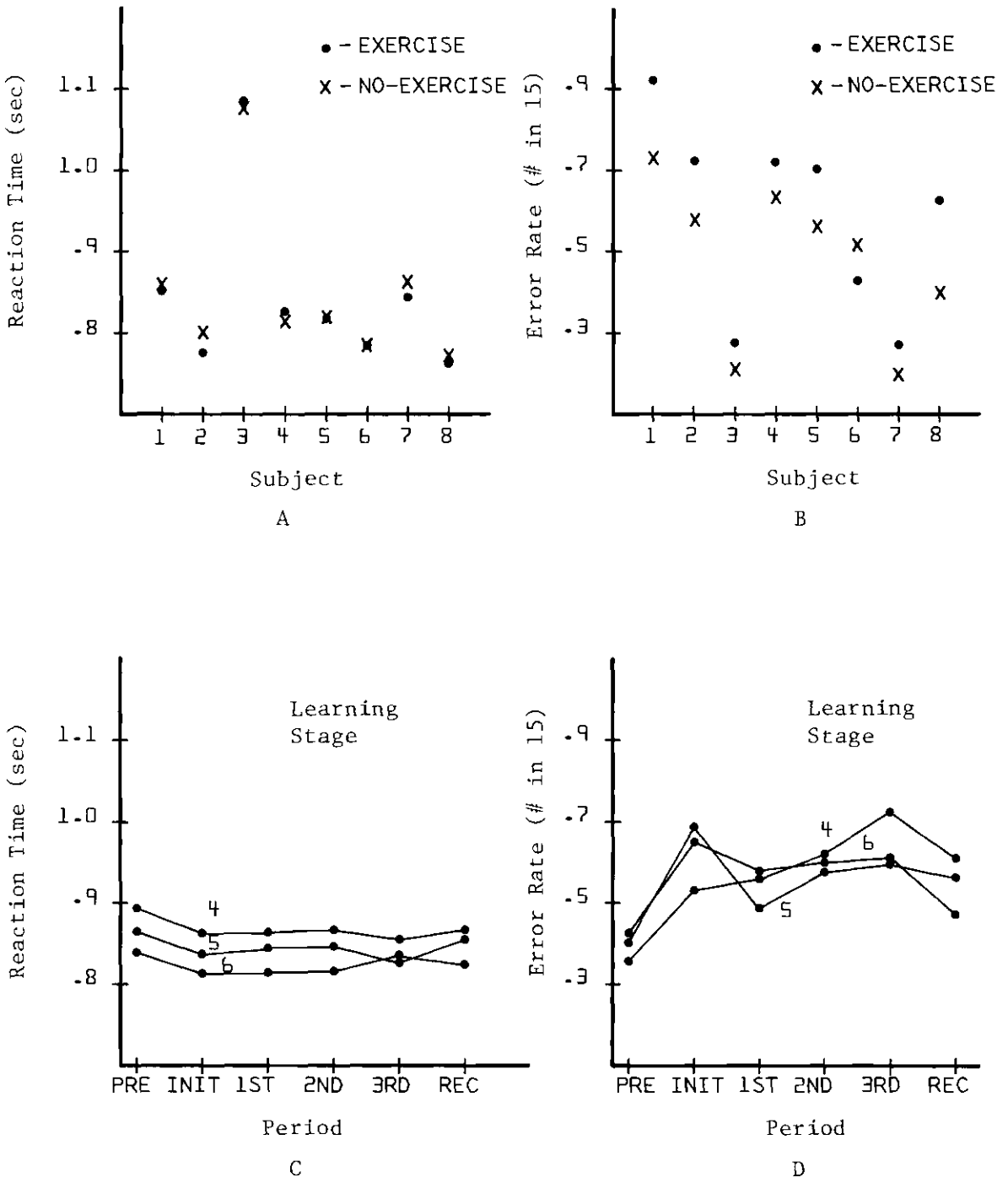
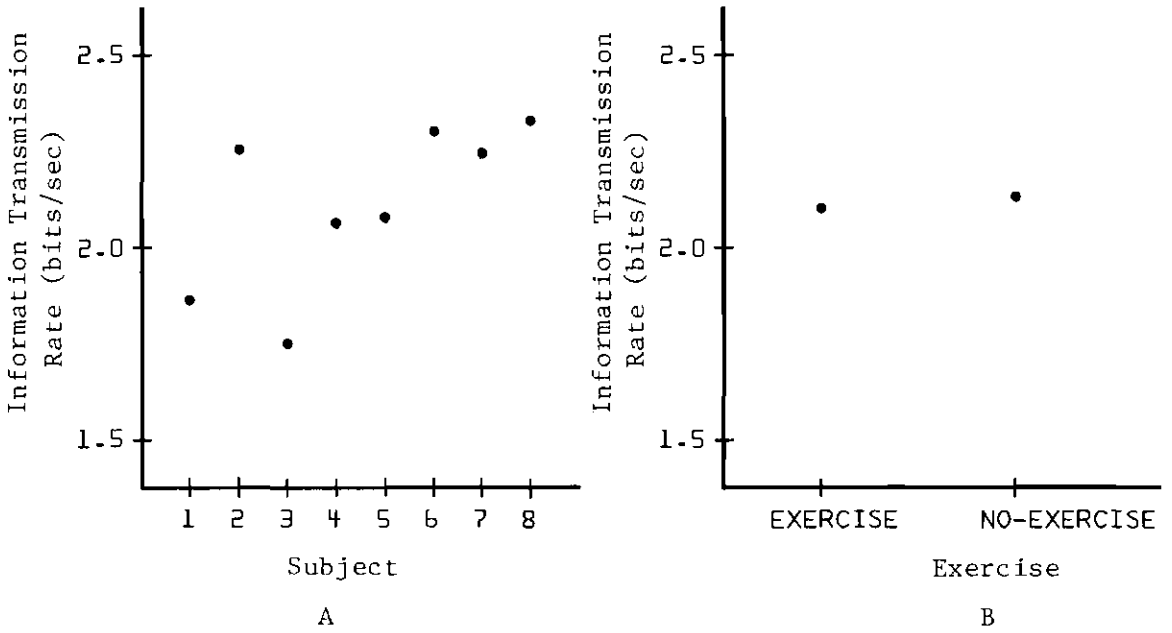


Figure 26. TSCRT -- Model III -- 1st Order Interactions



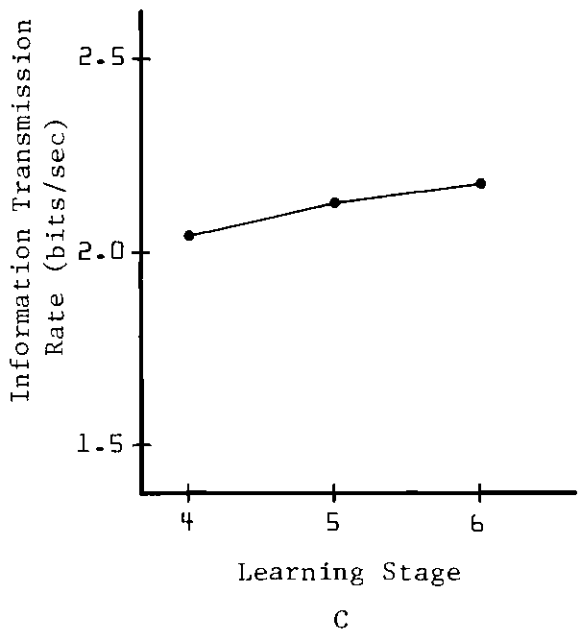


Figure 27. TSCRT -- Model III -- Information Transmission Rate

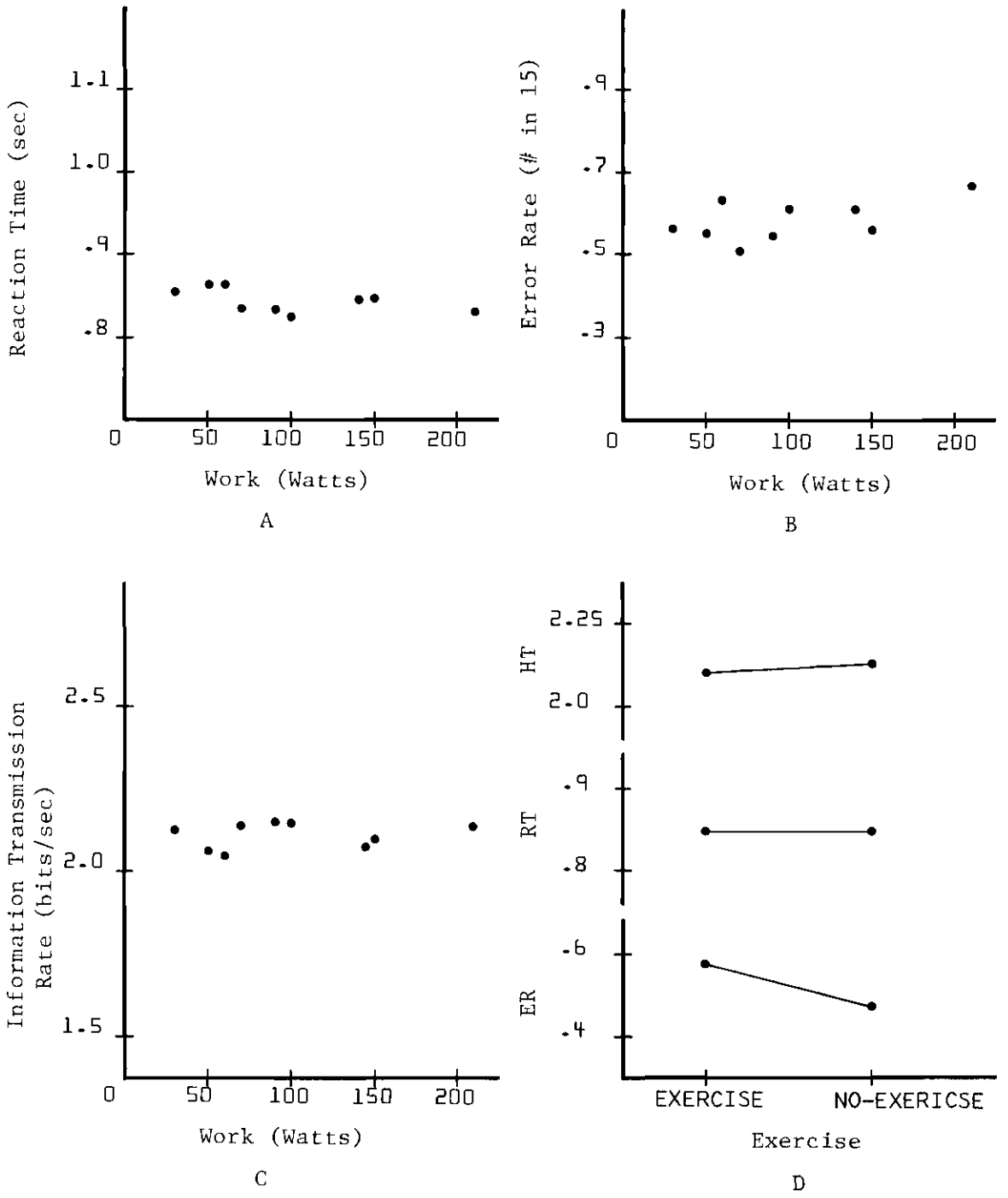


Figure 28. TSCRT -- Work Load Effects

a relatively high error rate; where as, those subjects with a relatively slow reaction time tended to have a relatively low error rate. This further indicated that at least part of the subject effect was due to the individual's strategy concerning the trade-off between speed and accuracy.

Learning Effect

The learning effect for reaction time on the SRT was found to be statistically significant for all three models (Tables 4, 5, and 6). A significant learning effect was observed during learning stage 1; however, no significant trend was observed during the remainder of the study (Figure 5D). This indicates that learning on the SRT was essentially completed during the first few test sessions.

The learning effect on the RT of the TSCRT was also found to be statistically significant for all three models (Tables 4, 5, and 6). The decrease in RT with learning appeared to have an exponential form since a large decrease in RT was noted during the early sessions and the rate of decrease in RT was noted during the early sessions and the rate of decrease gradually diminished during the remaining sessions (Figure 14C). This learning effect is attributed to actual learning that occurred on the TSCRT during the study.

The effect of learning on the error rate of the TSCRT was not significant (Tables 4, 5, and 6; Figures 14D, 19B and 23B). It appears that the subjects individually established for themselves a standard of accuracy (possibly in accordance with the Hypothesis of Par) during the initial test sessions. This accuracy strategy was then maintained relatively constant throughout the remainder of the study. Since the ER was held constant, the additional training on the task resulted in the previously noted decrease in RT.

The effects of learning on the information transmission rate was found to be statistically significant (Table 7). HT showed sustained improvement during Phase 3 (Figure 27C) which is in agreement with the above findings concerning reaction time and error rate. As RT decreased while ER remained fairly constant; HT increased.

Period Effect

The period effect on the reaction time of the SRT was found to be statistically significant in all three models (Tables 4, 5, and 6). In general, all SRT models showed a rather large increase in RT during the initial exercise period followed by a gradual decrease in RT throughout the remainder of the session: (Figure 5C, 9A, and 11C). It appeared that on the SRT the subjects were able to rapidly establish their activity-set during the pre-exercise period and since the cognitive stress was minimal, they were able to concentrate on the timing of the stimuli. As a result, they were able to remove a portion of the temperal uncertainty concering the arrival of the next stimulus. During the initial exericse period, the RT increased because the subjects had to divide their attention between the task and the exercise (had to adjust their activity-set to include the rate display), and in the process they lost the "timing" of the stimuli. The decrease in RT that occurred during the exercise periods resulted from the establishment of an "internal rhythm" such that the subject could maintain the exercise rate with less frequent observations of the rate display and could shift his attention back to the task. During recovery, with the exercise stress removed, the RT performance appraoched the pre-exercise performance with the remaining difference probably due to fatigue, boredom, or a feeling that the

session had ended when the exercise was terminated.

The period effect on the reaction time of the TSCRT was found to be statistically significant in all three models (Tables 4, 5 and 6). Since the periods were always tested in the same order (i.e.; pre, init, 1st, etc), any learning that occurred during the course of the session would also influence the period effect. This was the result shown in the period effect of Model I (Figure 14A) and in the period effect on the unlearned phase (top 3 curves of Figure 18C) where the continuous downward slope was primarily an indication of learning. The effects of learning seem to have outweighed the period effects. The period effect curves of the fully-learned phase (bottom three curves of Figure 18C) seemed to indicate the "true" period effect. These three curves, which were essentially parallel, indicated that RT decreased slightly during the exercise conditions.

The period effect on the error rate of the TSCRT was found to be statistically significant on Models I and II (Tables 4 and 6). The ER tended to increase sharply during the initial exercise period, decrease during the 1st third of exercise, then increase slightly during the remainder of the exercise (Figure 14B, 20D, and 24D). During the recovery period, a fairly large decrease in ER was noted.

For the TSCRT, the period effect of Model I involved a trade-off of speed and accuracy; in that, the RT was held relatively constant and the ER was allowed to fluctuate with the stress level of the various periods. It appeared that during the establishment of their activity-set for the pre-exercise period, the subjects set their response speed in accordance with their predetermined standard of accuracy and consistant

with their current stage of learning. This is indicated by the relatively small variation in ER for the pre-exercise period (Figure 18D) and the steady decline with learning in the RT for the pre-exercise period (Figure 18C). During the initial exercise period, the exercise stress and a slight decrease in RT caused a relatively large increase in ER (Figures 14A, 14B, 18C and 18D). Then, in general, the ER decreased during the 1st third of exercise as the subject readjusted his activity-set and developed his internal rate rhythm. During the last two-thirds of exercise, the ER tended to increase slightly while the RT was held relatively constant; possibly indicating the subject's response to additional stress caused by fatigue or boredom. During the recovery period, RT increased slightly and ER decreased significantly; possibly indicating the subject's attempt to adjust his activity-set to re-obtain his predetermined standard of accuracy.

The RT period effect on the SRT and the ER period effect on the TSCRT were different for the control/no-exercise conditions and for the exercise conditions (Figures 10B, 12D, 21D and 25D). The period effects for the exercise conditions corresponded to Model I, while the period effects for the control/no-exercise conditions seemed, in general, to gradually increase during the course of the test session, possibly in response to boredom. There was no appreciable difference in the RT period effects on the TSCRT between control/no-exercise conditions and exercise conditions (Figures 21C and 25C).

Force and Rate Effects

The effect of rate on the reaction time of the SRT was found to be statistically significant; where as, the force effect was not

(Table 4 and Figures 5A, 5B and 7A). RT was lowest for the 60 RPM rate and highest for the 90 RPM rate (Figure 7C). It seemed that the "internal rhythm" was easier to obtain at 60 RPM; thus, less cognitive processing was required to maintain 60 RPM than for 30 RPM and 90 RPM.

The force effect on the reaction time of the TSCRT was statistically significant; while the rate effect was not (Table 4). This was just the opposite of the SRT finding. However; neither the force nor the rate effect on the TSCRT appeared to be of practical importance since the curves did not show any significant trends (Figures 13A, 13C, 16A, 16C, 17A, 17C and 18A).

The rate effect on the error rate of the TSCRT was statistically significant and the force effect was not (Table 4). However, it appears that both the force effect and the rate effect were of practical importance. ER was higher for the 29.49 pound force than for the two lighter forces (Figure 13B). ER was highest for the 90 RPM rate and lowest for the 30 RPM rate (Figure 13D). The three exercise combinations involving 90 RPM and the exercise combination of 60 RPM and 29.49 pounds; each had a higher ER than any of the remaining combinations (Figure 18B). The 90 RPM rate created a large amount of task stress as indicated by the relatively large increase in ER during the entire exercise portion of the session (Figure 17D). The 29.49 pound force caused some fatigue as indicated by the relatively small increase in ER during the initial exercise period and the relatively steep increase in ER during the latter exercise portions of the session (Figure 17B). The preceding fast rate and heavy force effects were primarily prevalent during the unlearned portion of the study and tended to be eliminated

with training (Figure 16B and 16D).

The Effects of Exercise on Learning

An analysis of Model II detected a statistically significant control effect on the reaction time performance of both the SRT and the TSCRT (Table 5). However, it cannot be concluded that exercise does, in fact, affect the rate of learning. This discrepancy results from the fact that different subjects were used in the two conditions compared so that the large subject effect (as determined by Model I) is imbeded in the reported control effect. As illustrated by the graphs (Figures 10A and 21A), any difference in the rate of learning between the groups that may have initially been present, had been practically eliminated by learning stage 2. It appeared that on the TSCRT the difference between the average reaction time of each group is off-set by an opposite difference in average error rate for each group (Figure 19C and 19D). It appears that the rate of learning on the SRT or the TSCRT is not practically affected by simultaneous exercise.

The Effect of Simultaneous Exercise on the Performance of Fully Learned Subjects

The exercise effect of Model III was found to be statistically significant in the reaction time and error rate analysis of the TSCRT (Table 6). For the SRT, RT was approximately the same during exercise and no-exercise (Figure 11B); however, for the TSCRT, RT was slightly lower during exercise than during no-exercise (Figure 23C). All subjects, except one, had a lower error rate on the TSCRT while not exercising than they had while exercising (Figures 23D and 26B). HT was not significantly

affected by exercise (Figure 27B and Table 7).

The RT period effects were approximately identical for the exercise and the no-exercise conditions on both the SRT and the TSCRT (Figures 12D and 25C). Furthermore, for both tasks, the Model III period effect corresponds to the Model I period effect discussed previously.

The profiles of the ER period effects on the TSCRT for the exercise and the no-exercise conditions were different (Figure 25D). The ER during the pre-exercise period was the same for both conditions (again illustrating the predetermined standard of accuracy). For the exercise conditions, the ER increases substantially during the initial exercise period, recovered somewhat during the first-third of exercise, increased gradually during the last two-thirds of exercise, and decreased during recovery. This ER profile was discussed under Model I. For the no-exercise conditions, the ER increased gradually throughout the test session; possibly in response to a boredom effect.

There was no appreciable difference in the residual learning between the exercise and no-exercise conditions for both the SRT and the TSCRT (Figures 12C, 25A, and 25B).

The Inverted-U Hypothesis

The data obtained in this study does not support the inverted-U hypothesis of human performance. The previous discussion suggests that cognitive performance by trained subjects was not significantly affected by the level of simultaneous exercise. This fact is further illustrated by the TSCRT work effect graphs (Figure 28). These graphs indicated that RT (Figure 28A), ER (Figure 28B), and HT (Figure 28C) did not appreciably change for the various levels of simultaneous work load (40 - 210 watts)

used in this study. The composite work effect graph (Figure 28D) illustrated that the no-exercise decrease in ER and the increase in RT combined to cause a slight increase in the no-exercise HT. Therefore, in general, the inverted-U hypothesis cannot be supported.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The data seemed to support the hypothesis that, in general, man's cognitive performance on simple reaction tasks and on complex 2-bit choice reaction tasks as measured by reaction time and error rate is not significantly affected by simultaneous physical activity. Individuals who were not fully trained on the task experienced some decrement in performance, particularly for the heavier work loads. However, when fully trained, there was no significant differences in performance between the various levels of simultaneous exercise. The primary difference between exercise and no-exercise conditions for fully trained subjects was that the subjects were slightly faster, but made significantly more errors while performing under the exercise conditions.

It can be exepcted that the overall cognitive performance level, as measured by reaction time on simple reaction tasks and by reaction time and error rate on complex choice reaction tasks, will vary during the course of the work session. A relatively large performance decrement (increase in RT or ER) can be expected to occur during the initial portion of physical activity until the individual readjusts his activity-set to take into account the secondary stress associated with the simultaneous exercise. Also, during the latter portion of the session, performance on the primary task will show a slight decrease, due to the onset of fatigue. When the simultaneous physical activity is terminated, performance can be

expected to improve slightly. However, if the individual performs the primary task without the secondary stress associated with simultaneous physical activity, a performance decrement can also be expected during the latter portions of the session, possibly due to boredom. The final performance would approximate the final level obtained while exercising.

A significant learning effect was detected on the reaction time performance of a complex choice reaction task; however, error rate on the same task did not seem to be affected by learning. This finding seems to indicate that an individual establishes for himself some standard of accuracy and he sets his response time at the level required to obtain the desired error rate. Then, as his proficiency on the task increases, his reaction time becomes faster but his error rate remains relatively constant. However, when simultaneous physical activity (secondary stress) is superimposed on the task, the individual seems to shift his priorities. He holds his response time relatively constant and allows his error rate to vary with the total stress load. When the simultaneous physical activity is terminated, the individual once again attempts to set his response time at the level which corresponds to his pre-determined standard of accuracy.

The results found in this study definitely indicate possibilities for further research. A study should be designed to investigate the apparent shift in reaction time and error rate strategy between the pre-exercise period and the exercise periods. The instructions for the current study did not emphasize either speed or accuracy; so, the subjects were free to develop their own strategy. It would be interesting to

repeat the three-stage, choice reaction task portion of this study while emphasizing speed to one group of subjects and accuracy to another group of subjects. Then, by comparing their performance during the learning phase and during the fully learned phase, perhaps some conclusions could be reached concerning the effect of the speed-accuracy strategy on performance.

APPENDIX A

This appendix contains the experimental data averaged for each period of the test session. Table 9 contains the data of the simple reaction task (SRT). Table 10 contains the data of the three-stage, choice reaction task (TSCRT).

Table 9. SRT Data

(20 S-R Trials per Set)

Average Reaction Time (Sec per Stimulus)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
					Phase 1					
Subject 1										
1	12.64	30	20	.4648	.7758	.5173	.5256	.5453	.5300	.4893
3	29.49	90	3	.3192	.4901	.4901	.4528	.6185	.5205	.4058
5	21.07	90	6	.3458	.5998	.5400	.4500	.4042	.4647	.4344
7	12.64	90	20	.3032	.2951	.3027	.2836	.2673	.2863	.2568
9	29.49	60	12	.2097	.2507	.2462	.2373	.2608	.2481	.2137
11	21.07	60	20	.1955	.2601	.2385	.2124	.2047	.2205	.2200
13	12.64	60	20	.2270	.2627	.2315	.2185	.2229	.2239	.2201
15	29.49	30	20	.1758	.1822	.1950	.2114	.2063	.2036	.1992
17	21.07	30	20	.1922	.1939	.1934	.1987	.2001	.1947	.2036
Subject 2										
2	29.49	60	20	.1972	.2931	.2340	.2380	.2372	.2364	.2041
4	21.07	60	20	.2134	.2426	.2349	.2248	.2216	.2267	.1864
6	12.64	30	20	.2202	.2274	.2571	.2366	.2288	.2402	.2297
8	29.49	30	20	.2264	.2486	.2221	.1885	.1899	.1995	.2335
10	21.07	30	20	.2219	.2239	.1930	.1904	.1815	.1881	.2248
12	12.64	90	20	.1892	.2088	.2044	.2099	.2068	.2072	.1941
14	29.49	90	6	.1726	.2133	.2021	.2122	.2311	.2148	.1980
16	21.07	90	20	.1961	.2249	.2043	.1944	.1994	.1991	.1961
18	12.64	60	20	.1959	.2368	.2174	.2102	.2167	.2146	.2184
Subject 3										
1	29.49	30	20	.2756	.2951	.3097	.3057	.2900	.3405	.2490
3	21.07	90	12	.2771	.2985	.3013	.3233	.2947	.3064	.2375
5	12.64	90	20	.2778	.3101	.2700	.2754	.2701	.2716	.2085
7	29.49	90	4	.2444	.2653	.2734	.2869	.3250	.2897	.2299
9	21.07	60	20	.2250	.2881	.2930	.2805	.2513	.2737	.2220
11	12.64	60	20	.2307	.2606	.2431	.2346	.2455	.2414	.2412
13	29.49	60	15	.2168	.2422	.2299	.2474	.2552	.2442	.2152
15	21.07	30	12	.2428	.2902	.2714	.2603	.2434	.2583	.2315
17	12.64	30	20	.2302	.2049	.2495	.2460	.2474	.2477	.2350

Table 9. SRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
					Phase I					
Subject 4										
1	21.07	90	6	.2231	.3369	.2948	.3269	.3561	.3259	.2248
4	12.64	90	20	.1991	.3951	.2964	.2414	.2304	.2547	.1566
6	29.49	60	12	.2054	.2423	.2148	.2211	.2525	.2295	.1921
8	21.07	60	20	.2270	.2280	.2263	.2284	.2238	.2262	.2213
10	12.64	60	20	.1917	.2333	.2084	.2027	.2105	.2072	.1900
12	29.49	30	20	.2065	.2317	.2227	.2102	.2081	.2138	.1879
14	21.07	30	20	.1889	.1911	.2040	.1760	.1957	.1987	.1930
16	12.67	30	20	.1836	.2199	.2082	.1947	.1879	.1970	.1836
18	29.49	90	6	.2078	.2254	.2264	.2443	.2558	.2422	.2099
Subject 5										
1	21.07	60	20	.2043	.2768	.2694	.2567	.2560	.2603	.2424
2	12.64	30	20	.2143	.2547	.2181	.2065	.2120	.2119	.2064
5	29.49	30	20	.2116	.2466	.2276	.2141	.2383	.2266	.2238
7	21.07	30	20	.2218	.2318	.2205	.2168	.2163	.2179	.2276
9	12.64	90	20	.2276	.2401	.2290	.2227	.2015	.2175	.1814
11	29.49	90	6	.1963	.2185	.2045	.1800	.1769	.1871	.1829
13	21.07	90	12	.2073	.2149	.2072	.1933	.2009	.2005	.1983
15	12.64	60	20	.2024	.2180	.1950	.1957	.1959	.1955	.1911
17	29.49	60	20	.1981	.2192	.2079	.1930	.2054	.2026	.1983
Subject 6										
2	12.63	90	20	.2028	.2857	.2463	.2227	.2126	.2252	.1987
4	29.49	90	6	.2257	.2175	.2133	.1935	.2013	.2027	.2300
6	21.07	60	20	.2131	.2206	.2217	.2112	.2194	.2175	.1943
8	12.64	60	20	.1791	.2256	.2082	.2038	.1980	.2033	.1663
10	29.49	60	15	.2020	.1995	.1985	.1923	.1964	.1958	.2024
12	21.07	30	20	.2156	.2232	.2087	.2060	.2046	.2064	.2183
14	12.64	30	20	.1954	.2015	.2107	.1910	.1998	.2001	.2027
16	29.49	30	20	.1932	.2125	.2054	.2000	.2236	.2101	.2177
18	21.07	90	20	.2196	.2414	.2163	.2178	.2183	.2175	.2111

Table 9. SRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
					Phase 1					
Subject 7										
1	12.64	90	20	.2636	.3172	.2757	.2469	.2537	.2579	.2410
3	29.49	60	9	.2069	.2419	.2283	.2095	.2029	.2136	.2030
5	21.07	60	20	.1923	.2311	.2197	.2418	.2350	.2311	.2098
7	12.64	60	20	.2152	.2377	.2357	.2279	.2189	.2275	.1837
9	29.49	30	20	.2141	.2289	.2270	.2286	.2300	.2285	.2173
11	21.07	30	20	.2258	.2211	.2172	.2204	.2293	.2224	.2333
13	12.64	30	20	.2189	.2407	.2002	.2320	.2486	.2267	.2346
15	29.49	90	5	.2335	.2371	.2375	.2287	.2433	.2379	.2280
17	21.07	90	9	.2382	.2375	.2312	.2266	.2326	.2301	.2281
Subject 8										
1	21.07	30	20	.1392	.3290	.2267	.1645	.1439	.1492	.1228
3	29.49	30	20	.1395	.1814	.1750	.1717	.1646	.1701	.1448
6	12.64	90	20	.1854	.2208	.1943	.1817	.1825	.1858	.1548
8	29.49	90	8	.1600	.1670	.1792	.1793	.1804	.1797	.1607
10	21.07	90	20	.2085	.1634	.1732	.1687	.1702	.1706	.1840
12	12.64	60	20	.1967	.1794	.1759	.1709	.1749	.1738	.2070
14	29.49	60	12	.1827	.1651	.1624	.1826	.1799	.1750	.1892
16	21.07	60	20	.2002	.1621	.1660	.1631	.1776	.1691	.1945
18	12.64	30	20	.1817	.1510	.1457	.1655	.1604	.1558	.1806
Subject 9										
2			13	.1973	.2168	.2134	.2235	.2290	.2228	.2071
4			20	.2012	.1957	.1978	.2096	.1953	.2003	.1790
6			12	.1916	.1823	.2169	.2233	.2266	.2223	.2103
8			20	.1959	.1597	.2057	.2286	.2224	.2184	.2359
10			20	.2157	.2312	.2100	.2200	.2071	.2120	.1814
12			20	.2423	.2087	.2050	.2184	.2075	.2099	.2192
14			20	.2052	.2024	.2079	.2228	.2106	.2133	.1962
16			20	.2105	.2047	.2144	.2073	.2248	.2159	.2151
18			20	.2006	.2111	.2059	.1947	.2024	.2013	.2170

Table 9. SRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
					Phase 1					
Subject 10										
1			20	.2104	.2038	.2214	.2474	.2225	.2309	.2406
4			20	.2021	.2213	.2270	.2319	.2172	.2253	.2192
6			12	.1906	.2318	.2020	.1960	.1983	.1988	.2041
8			20	.2046	.1897	.1969	.1912	.2021	.1970	.1951
10			15	.1899	.1774	.1962	.2186	.2223	.2124	.2152
12			20	.1887	.1971	.1953	.1971	.1847	.1921	.1993
14			20	.1966	.2252	.2175	.2220	.2150	.2180	.2184
16			20	.2064	.2116	.2106	.1996	.1987	.2031	.1920
18			20	.1901	.1883	.1924	.2000	.1852	.1922	.1977
Subject 11										
2			20	.2671	.2109	.2258	.2508	.2203	.2205	.2226
4			20	.2099	.2063	.2190	.2181	.2125	.2164	.2234
6			20	.1964	.1931	.1881	.1979	.1713	.1852	.2247
8			20	.1977	.2131	.2050	.2100	.1999	.2047	.2054
10			20	.1948	.1973	.2013	.2093	.2118	.2074	.2083
12			20	.2299	.2552	.2359	.2339	.2277	.2359	.2213
14			20	.2190	.2152	.1996	.2156	.2163	.2102	.2174
16			20	.2274	.2199	.2427	.2380	.2244	.2349	.2326
18			20	.2219	.2347	.2247	.2096	.2228	.2195	.2193

Table 9. SRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
				Phase 3					
Subject 1									
25	12.64	30	20	.1947	.2381	.2204	.2292	.2209	.2332	.2170
39	12.64	60	20	.2248	.2564	.2436	.2335	.2311	.2362	.2500
31	12.64	90	20	.2340	.2626	.2507	.2214	.2279	.2339	.2217
43	21.07	30	20	.2431	.2449	.2541	.2207	.2202	.2322	.2307
37	21.07	60	20	.2260	.2558	.2364	.2247	.2034	.2213	.1930
29	21.07	90	13	.2229	.2717	.2435	.2638	.2880	.2635	.2252
41	29.49	30	20	.2130	.2639	.2391	.2219	.2319	.2314	.2318
33	29.49	60	13	.2289	.2302	.2236	.2288	.2509	.2336	.2390
27	29.49	90	3	.2139	.2394	.2349	.2733	.2703	.2610	.2155
35			20	.2255	.2416	.2512	.2596	.2541	.2547	.2614
45			20	.2305	.2344	.2370	.2334	.2375	.2361	.2363
Subject 2									
30	12.64	30	20	.2014	.2213	.2263	.2272	.2155	.2228	.2132
44	12.64	60	20	.2086	.2313	.2258	.2198	.2232	.2231	.2246
38	12.64	90	20	.2008	.2187	.2109	.2179	.2185	.2157	.2167
36	21.07	30	20	.1809	.2056	.2118	.2245	.2218	.2191	.2282
28	21.07	60	20	.2019	.2264	.2149	.2215	.2199	.2186	.2128
42	21.07	90	20	.2186	.2277	.2260	.2150	.2183	.2200	.2153
32	29.49	30	20	.2032	.2185	.2087	.2048	.1986	.2040	.2011
26	29.49	60	20	.2025	.2538	.2357	.2178	.2222	.2256	.2370
40	29.49	90	7	.1936	.2337	.2260	.2439	.2304	.2324	.2105
35			20	.1898	.1992	.1999	.2027	.2039	.2021	.1996
46			20	.2037	.2110	.2048	.2002	.2095	.2051	.2124
Subject 3									
43	12.64	30	20	.2219	.2519	.2432	.2373	.2509	.2441	.2366
37	12.64	60	20	.2294	.2426	.2436	.2282	.2350	.2360	.2299
29	12.64	90	20	.2234	.2522	.2471	.2484	.2463	.2472	.2559
39	21.07	30	20	.2031	.2391	.2326	.2353	.2348	.2342	.2277
31	21.07	60	20	.2421	.2544	.2432	.2419	.2468	.2441	.2475
27	21.07	90	12	.2276	.2576	.2305	.2346	.2377	.2343	.2530
25	29.49	30	20	.2389	.2408	.2513	.2433	.2408	.2452	.2357
41	29.49	60	20	.2206	.2571	.2582	.2332	.2485	.2473	.2512

Table 9. SRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
					Phase 3					
Subject 3										
33	29.49	90	6	.2249	.2347	.2451	.2459	.2521	.2477	.2472
35			20	.2350	.2584	.2503	.2473	.2380	.2451	.2354
45			20	.2324	.2359	.2392	.2348	.2426	.2401	.2421
Subject 4										
42	12.64	30	20	.1924	.2090	.2025	.1991	.1990	.2002	.1901
36	12.64	60	20	.2037	.2100	.2136	.2113	.2156	.2136	.2165
28	12.64	90	20	.2180	.2393	.2245	.2168	.2117	.2177	.1971
40	21.07	30	20	.2005	.2197	.2162	.2100	.2122	.2129	.1916
32	21.07	60	20	.1963	.2184	.2071	.2097	.2108	.2092	.1992
26	21.07	90	15	.2077	.2264	.2178	.2005	.1963	.2048	.1991
38	29.49	30	20	.1990	.2157	.2237	.2136	.2157	.2178	.1749
30	29.49	60	15	.1964	.2123	.2088	.2108	.2026	.2074	.1967
44	29.49	90	6	.2027	.2240	.2223	.2197	.2191	.2204	.1860
34			20	.2002	.1948	.1980	.2049	.2134	.2054	.1870
46			20	.1993	.2131	.2055	.2078	.2033	.2054	.2007
Subject 5										
33	12.64	30	20	.1676	.1949	.2094	.2256	.2044	.2125	.1792
39	12.64	60	20	.1757	.2206	.2017	.2015	.1945	.1992	.1907
31	12.64	90	20	.1866	.2603	.2251	.2072	.2148	.2161	.1948
29	21.07	30	20	.1961	.2369	.2177	.2098	.1995	.2090	.2877
25	21.07	60	20	.2300	.2465	.2310	.2251	.2240	.2268	.2240
41	21.07	90	12	.1924	.2093	.2064	.2011	.1954	.2009	.1763
27	29.49	30	20	.2332	.2439	.2341	.2187	.2151	.2228	.2110
43	29.49	60	12	.1864	.2159	.2123	.1852	.1923	.1966	.1780
37	29.49	90	6	.1739	.2010	.2065	.2029	.2086	.2060	.1672
35			20	.2056	.2283	.2122	.2150	.1892	.2050	.1702
45			20	.1855	.1723	.1711	.1806	.1858	.1812	.1774

Table 9. SRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
					Phase 3					
Subject 6										
40	12.64	30	20	.1744	.2305	.2166	.2085	.2041	.2098	.2177
32	12.64	60	20	.1814	.2118	.1970	.1909	.1998	.1961	.2210
26	12.64	90	20	.2201	.2250	.2166	.2244	.2273	.2227	.2266
36	21.07	30	20	.1882	.2234	.2175	.2163	.2061	.2132	.2010
30	21.07	60	20	.2061	.2181	.2007	.2130	.2001	.2042	.2059
44	21.07	90	20	.2040	.2345	.2190	.2149	.2231	.2192	.2203
42	29.49	30	20	.1865	.2174	.2173	.2271	.2340	.2261	.2274
38	29.49	60	20	.1978	.2310	.2117	.1792	.1826	.1918	.1934
28	29.49	90	6	.2257	.2370	.2260	.2315	.2282	.2286	.2185
34			20	.2041	.2124	.2266	.2199	.2148	.2204	.2181
46			20	.2046	.2381	.2170	.2086	.2210	.2159	.2364
Subject 7										
39	12.64	30	20	.2391	.2324	.2391	.2373	.2346	.2370	.2483
31	12.64	60	20	.2399	.2505	.2532	.2381	.2408	.2444	.2332
25	12.64	90	20	.2315	.2348	.2409	.2405	.2473	.2430	.2604
37	21.07	30	20	.2463	.2491	.2359	.2284	.2365	.2339	.2350
29	21.07	60	20	.2258	.2389	.2367	.2457	.2460	.2426	.2508
43	21.07	90	12	.2460	.2296	.2333	.2335	.2314	.2327	.2345
33	29.49	30	20	.2268	.2396	.2475	.2354	.2346	.2394	.2477
27	29.49	60	12	.2214	.2018	.2213	.2240	.2248	.2234	.2282
41	29.49	90	5	.2494	.2220	.2275	.2282	.2206	.2249	.2352
35			20	.2450	.2479	.2481	.2633	.2520	.2540	.2453
45			20	.2424	.2494	.2492	.2500	.2522	.2505	.2498
Subject 8										
44	12.64	30	20	.1949	.1790	.1900	.1915	.1801	.1870	.1922
38	12.64	60	20	.1970	.1631	.1702	.1758	.1804	.1755	.2028
30	12.64	90	20	.1921	.1906	.1889	.1899	.1921	.1903	.2053
28	21.07	30	20	.1967	.1802	.1858	.1928	.1747	.1840	.1984
42	21.07	60	20	.1862	.1706	.1817	.2094	.2019	.1917	.1880
36	21.07	90	20	.1958	.1872	.1833	.1835	.1887	.1850	.1922
26	29.49	30	20	.2007	.1909	.1962	.1992	.2000	.1984	.2081
40	29.49	60	20	.1813	.1826	.1743	.1738	.1805	.1763	.1914
32	29.49	90	20	.2094	.1955	.1974	.1941	.1916	.1944	.1945
34			20	.1984	.2077	.2009	.2076	.1966	.2014	.2023
46			20	.1897	.1902	.1945	.1886	.1920	.1919	.2021

Table 10. TSCRT Data

(15 S-R Trials per Set)

Average Reaction Time (Sec per Stimulus)
Average Error Rate (Errors per 15 S-R Trials)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
					Phase 1					
Subject 1										
2	21.07	60	20	1.6185	1.5762	1.5357	1.3210	1.2386	1.3566	1.2079
				1.50	1.00	.333	0.00	.286	.200	.500
4	12.64	60	20	1.2281	1.3637	1.3173	1.2390	1.1489	1.2309	1.1225
				0.00	2.00	.500	.143	.715	.450	0.00
6	29.49	30	20	1.2243	1.1460	1.1395	1.1281	1.0580	1.1058	1.0650
				.500	0.00	.167	.571	.571	.450	0.00
8	21.07	30	20	1.0724	1.1329	1.1067	1.0530	1.0312	1.0631	1.0133
				1.00	1.00	.333	.429	.167	.316	1.00
10	12.64	30	20	1.0410	1.0950	1.0535	1.0028	1.0016	1.0176	.9511
				.500	0.00	.500	.144	.429	.350	.500
12	29.49	90	3	1.0517	1.0693	1.0693	1.0108	1.0420	1.0407	.9572
				.500	3.00	3.00	2.00	2.00	2.33	2.50
14	21.07	90	6	1.0372	1.0790	1.0123	.9585	1.0081	.9929	.9712
				1.50	1.00	2.50	3.50	2.00	2.67	1.00
16	12.64	90	20	.9627	1.0144	.9814	.9457	.8736	.9361	.9334
				1.00	1.00	2.571	1.00	.667	1.474	1.50
18	29.49	60	12	1.0985	.9310	.9306	.9305	.8929	.9180	.9797
				2.00	1.00	1.50	.750	1.25	1.167	.500

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
					Phase 1					
Subject 2										
1	21.07	30	20	1.2614	1.1781	1.2175	1.0877	1.0365	1.1098	1.0385
				.500	0.00	.667	.333	1.00	.684	1.50
3	12.63	90	20	1.0402	1.0457	1.0297	1.0027	.9722	1.0016	.9703
				0.00	4.00	1.167	.429	.667	.737	1.00
5	29.49	90	6	.9691	.8862	.9272	.9700	.9700	.9559	.9773
				0.00	3.00	3.50	.500	3.50	2.50	0.00
7	21.07	90	20	.9475	.9672	.9961	.9207	.9001	.9271	.8838
				.500	1.00	.833	.857	1.00	.900	1.00
9	12.63	60	20	.9378	.9126	.8941	.8657	.8788	.8789	.8537
				1.50	1.00	.500	1.14	1.43	1.05	0.00
11	29.49	60	20	.8804	.8856	.8659	.8466	.8151	.8414	.8451
				.500	2.00	1.50	.857	1.14	1.15	.500
13	21.07	60	20	.8396	.7756	.8095	.8108	.8351	.8189	.7870
				0.00	0.00	2.67	2.00	1.29	1.33	1.00
15	12.63	30	20	.8225	.8141	.8102	.8254	.8347	.8241	.8166
				.500	0.00	1.167	.714	1.00	.950	1.00
17	29.49	30	20	.8534	.8679	.8361	.8201	.8299	.8283	.8760
				1.00	1.00	.833	.857	.714	.800	0.00
Subject 3										
2	12.64	60	15	1.5476	1.5461	1.4820	1.4470	1.3877	1.4389	1.2334
				.500	1.00	.400	.400	.200	.333	.500
4	29.49	60	12	1.3645	1.3849	1.3367	1.2965	1.2959	1.3097	1.3255
				0.00	0.00	.750	0.00	0.00	.333	0.00
6	21.07	30	20	1.2650	1.3859	1.3007	1.3218	1.2629	1.2938	1.3114
				.500	0.00	.286	.167	0.00	.150	0.00
8	12.16	30	20	1.2460	1.2190	1.2724	1.2980	1.2664	1.2780	1.3093
				0.00	0.00	0.00	.333	.143	.150	.500
10	29.49	30	20	1.1977	1.1987	1.2558	1.2478	1.2877	1.2646	1.2039
				.500	1.00	.286	0.000	0.00	.100	0.00
12	21.07	90	12	1.2203	1.2599	1.1773	1.1595	1.1657	1.1675	1.1876
				.500	0.00	0.00	.250	.250	.167	0.00
14	12.64	90	20	1.2803	1.1631	1.2033	1.2130	1.2062	1.2072	1.2415
				0.00	1.00	.143	.167	.143	.15	.500
16	29.49	90	4	1.1850	1.2197	1.2112	1.4988	1.2237	1.2863	1.2440
				0.00	1.00	.500	1.00	0.00	.500	0.00
18	21.07	60	20	1.2076	1.2324	1.1856	1.1940	1.1960	1.1908	1.2073
				0.00	0.00	.286	0.00	0.00	.100	0.00

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
					Phase 1					
Subject 4										
2	12.64	60	20	1.3094	1.3185	1.1982	1.1490	1.1159	1.1522	1.1164
				1.00	0.00	.167	.571	.429	.400	0.00
3	29.49	30	20	1.1524	1.1241	1.1029	1.1187	1.0492	1.0896	1.0429
				0.00	1.00	.667	.143	.429	.400	0.00
5	21.07	30	20	1.0856	1.1344	1.0550	1.0339	1.0015	1.0289	.9947
				.500	1.00	.500	.143	.571	.450	0.00
7	12.64	30	20	.9948	1.0927	.9991	.9905	.9938	.9943	.9946
				1.00	1.00	.167	.429	.571	.450	0.00
9	29.49	90	6	.9878	1.0199	1.0237	.9982	1.0044	1.0087	.9469
				1.00	1.00	.500	1.00	1.00	.833	0.00
11	21.07	90	20	1.0177	1.0034	.9478	.8942	.8882	.9082	.8619
				.500	2.00	1.33	1.29	1.14	1.25	1.00
13	12.64	90	20	.8692	.9234	.8993	.8873	.8836	.8787	.8692
				1.50	1.00	1.00	1.33	.571	.947	.500
15	29.49	60	12	.8808	.8828	.9032	.8519	.8952	.8834	.8699
				0.00	1.00	1.00	1.25	1.50	1.25	1.00
17	21.07	60	20	.8871	.8983	.8615	.8612	.8456	.8559	.8862
				.500	0.000	.857	1.00	.857	.900	0.00
Subject 5										
3	29.49	90	6	1.0791	1.1890	1.1576	1.1201	1.0880	1.1222	1.0513
				1.00	1.00	1.00	.500	.500	.667	1.00
4	21.07	90	12	1.0913	1.1708	1.0661	1.0210	1.0146	1.0339	.9943
				.500	1.00	1.00	.750	.500	.750	0.00
6	12.64	60	20	1.0178	1.0365	1.0169	1.0151	.9923	1.0073	.9253
				.500	0.00	1.00	.500	.429	.632	.500
8	29.49	60	20	1.0199	1.0500	.9835	.9763	.9853	.9819	.9387
				0.00	0.00	.667	.167	.286	.368	0.00
10	21.07	60	20	1.0040	.9448	.9373	.9178	.9610	.9387	.9015
				0.00	0.00	0.00	.500	.500	.316	0.00
12	12.64	30	20	.9550	.9734	.9410	.9172	.9053	.9203	.9120
				.500	0.00	.333	.333	.714	.474	1.00
14	29.64	30	20	.9664	.9750	.9462	.9419	.9263	.9379	.8867
				.500	0.00	0.00	.167	.143	.100	.500
16	21.07	30	20	.9564	.9680	.9155	.9150	.9065	.9122	.8915
				0.00	1.00	.429	0.00	.286	.250	.500
18	12.64	90	20	.9392	.9289	.9232	.9178	.9307	.9242	.9073
				.500	0.00	.857	.833	.511	.750	0.00

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
					Phase 1					
Subject 6										
1	29.49	60	9	1.2320	1.0706	1.1141	1.0429	1.0234	1.0647	1.0324
				1.50	1.00	.500	1.33	2.00	1.222	1.00
3	21.07	30	20	1.0496	1.07018	1.0075	.9823	.9879	.9918	.9881
				.500	0.00	.167	.286	.143	.200	0.00
5	12.64	30	20	1.1630	1.0232	.9864	.9542	.9538	.9648	.9768
				1.00	1.00	.500	.600	.143	.389	.500
7	29.49	30	20	.9039	.9159	.8948	.9287	.9055	.9087	.9049
				0.00	1.00	1.57	.167	.143	.650	.500
9	21.07	90	12	.9166	.9132	.9212	.8856	.8954	.9007	.9436
				.500	0.00	.750	.500	.500	.583	.500
11	12.64	90	20	.8790	.9436	.9070	.9261	.9015	.9100	.8560
				0.00	1.00	.571	.800	.429	.579	0.00
13	29.49	90	7	.9625	.9240	.9067	.9113	.8427	.8897	.8766
				.500	0.00	.300	1.00	1.00	.714	1.00
15	21.07	60	20	.9138	.8666	.8522	.8509	.8787	.8611	.9247
				0.00	0.00	.143	.333	.286	.25	.500
17	12.64	60	20	.9062	.9067	.8824	.8977	.8632	.8803	.8729
				.500	0.00	.143	.167	.571	.3	0.00
Subject 7										
2	21.07	30	20	1.8570	1.6159	1.5017	1.3357	1.1895	1.3340	1.1745
				0.00	3.00	.833	.143	.143	.400	0.00
4	12.64	30	20	1.0943	1.0320	1.0621	1.0807	1.0653	1.0698	1.0491
				0.00	1.00	1.167	.571	.571	.450	1.00
6	29.49	90	4	1.0753	1.0950	1.1050	1.1006	1.2238	1.1336	1.1281
				.500	1.00	.500	1.00	1.00	1.00	0.00
8	21.07	90	12	1.1211	1.0876	1.0352	.9932	1.0535	1.0273	.9776
				0.00	0.00	0.00	1.50	.750	.750	0.00
10	12.64	90	20	1.0709	1.0313	1.0189	1.0008	.9626	.9934	.9536
				0.00	0.00	0.00	.167	.714	.300	0.00
12	29.49	60	12	1.0125	1.0736	1.0266	.9677	.9282	.9742	.9661
				0.00	0.00	0.00	.250	.250	.167	.500
14	21.07	60	20	1.0076	.9752	.9620	.9262	.9069	.9320	.9287
				0.00	0.00	.143	0.00	.143	.100	0.00
16	12.64	60	20	.9879	.9115	.9082	.9409	.9140	.9200	.9375
				.500	0.00	0.00	.500	.286	.250	0.00
18	29.49	30	20	.9379	.9369	.9097	.9226	.9129	.9147	.9245
				.000	0.00	0.00	.167	.286	.150	.500

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
					Phase 1					
Subject 8										
2	21.07	90	13	1.1890	1.1406	1.0598	1.0418	.9709	1.0202	.9801
				1.00	1.00	.750	.500	.800	.692	0.00
4	12.64	60	20	1.0403	.9583	.9662	.9843	.9421	.9641	.9031
				.500	1.00	.167	.286	.143	.200	0.00
5	29.49	60	20	.9638	.9168	.8825	.8888	.9021	.8915	.8693
				0.00	0.00	.167	.857	.286	.450	.500
7	21.07	60	20	.9398	.9314	.9346	.8960	.8737	.8998	.8542
				1.00	0.00	.333	.857	1.14	.800	.500
9	12.64	30	20	.9052	.8802	.8864	.8649	.8549	.8679	.8316
				1.00	2.00	.500	.571	.286	.450	.500
11	29.49	30	20	.8906	.8226	.8985	.8192	.8027	.8162	.8097
				0.00	0.00	.167	.571	.286	.350	1.00
13	21.07	30	20	.8308	.7790	.7926	.8126	.8020	.8029	.7854
				0.00	1.00	.500	1.00	.833	.750	.500
15	12.64	90	20	.8387	.7781	.8239	.8079	.7804	.8031	.7745
				.500	1.00	.833	1.00	.857	.900	1.00
17	29.49	90	12	.8285	.8034	.7820	.7713	.7640	.7724	.7394
				0.00	1.00	1.00	.750	1.00	.917	.500
Subject 9										
1			20	1.5389	1.1140	1.4269	1.2803	1.2353	1.3085	1.1295
				.500	0.00	.500	.714	.571	.600	.500
3			20	1.1896	1.0419	1.1161	1.1341	1.0800	1.1076	1.0691
				.500	0.00	1.00	1.00	.857	1.00	.500
5			20	1.0977	1.0175	1.0511	1.0478	1.0453	1.0481	.9959
				.500	0.00	.071	1.50	.571	.700	1.50
7			20	1.0121	1.0472	1.0295	1.0542	1.0054	1.0285	1.0110
				1.00	0.00	.429	1.00	1.00	.800	1.0
9			20	0.9493	.9564	.9838	.9959	.9782	.9855	.9629
				1.00	0.00	.429	.500	.286	.400	1.00
11			20	1.0165	1.0135	.9821	.9754	.9866	.9817	.9625
				1.00	1.00	.429	.500	.714	.550	.500
13			20	.9584	.9202	.9322	.9265	.9182	.9256	.9114
				.500	0.00	.571	.500	1.00	.700	0.00
15			20	.9092	.8653	.9396	.9278	.9259	.9313	.9118
				0.00	1.00	1.143	.667	.714	.850	0.00
17			20	.9470	.8942	.9034	.9221	.8908	.9046	.8987
				1.50	1.00	1.43	.667	1.86	1.35	1.50

Table 10. TSCRT Data (Continued)

Session	Force (Lbs) Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery
				Phase 1					
Subject 10									
2		20	1.2626	1.1757	1.1314	1.0866	1.0835	1.0990	1.0703
			1.50	1.00	.833	.857	.428	.700	1.00
3		20	1.0088	.9862	1.0092	1.0270	.9891	1.0083	.9453
			0.00	0.00	.167	.429	.429	.350	.500
5		20	.9895	.9950	.9732	.9769	.9606	.9701	.9611
			.500	1.00	.500	.143	.286	.300	.500
7		20	.9783	.9692	.9516	.9594	.9282	.9458	.8982
			0.00	0.00	.571	.167	.750	.400	.500
9		20	.8912	.9482	.9293	.8997	.9010	.9105	.8767
			0.00	1.00	.571	.333	.286	.400	0.00
11		20	.8883	.8798	.8902	.9177	.8894	.8982	.9047
			.500	0.00	.429	.333	.429	.400	.500
13		20	.8867	.9139	.8891	.8814	.8851	.8854	.9090
			0.00	0.00	.286	.667	.571	.500	0.00
15		20	.8593	.8841	.8681	.8744	.8879	.8769	.5559
			1.00	0.00	.571	.500	.571	.550	0.00
17		20	.8759	.8574	.8484	.8667	.8587	.8575	.8742
			1.00	0.00	.143	.500	.571	.400	0.00
Subject 11									
1		20	1.7142	1.4442	1.4267	1.4286	1.3896	1.4143	1.3491
			.500	0.00	.429	.833	.857	.700	0.00
3		20	1.3469	1.2942	1.3087	1.3250	1.2574	1.2957	1.2726
			1.50	1.00	.571	.500	.428	.500	.500
5		20	1.2164	1.2215	1.2320	1.2431	1.2180	1.2304	1.2328
			.500	1.00	.571	.667	.429	.550	.500
7		20	1.2687	1.1808	1.2084	1.2423	1.2087	1.2187	1.2011
			.500	0.00	.286	.833	.714	.600	0.00
9		20	1.1570	1.1774	1.1673	1.1862	1.1599	1.1704	1.1788
			0.00	2.00	.875	.167	.571	.550	1.00
11		20	1.1482	1.1591	1.1451	1.1520	1.1498	1.1488	1.1116
			0.00	0.00	.429	.333	.143	.300	.500
13		20	1.1004	1.1333	1.1511	1.1444	1.1133	1.1350	1.0717
			.500	0.00	.500	.250	.714	.526	.500
15		20	1.1188	1.1226	1.1305	1.1089	1.1109	1.1172	1.1237
			0.00	0.00	.286	.167	.571	.350	.500
17		20	1.1050	1.0971	1.1004	1.1112	1.0914	1.1005	1.0631
			.500	0.00	.143	.167	.429	.250	1.50

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery	Info Rate
						Phase 2					
Subject 1											
19			13	.9092	.9093	.9180	.8822	.9301	.9107	.9221	
				2.50	2.00	1.40	1.50	2.00	1.615	2.00	
20			20	.8471	.9350	.9071	.9268	.9490	.9276	.9364	
				1.00	1.00	1.00	.667	1.167	.944	1.00	
21			20	.9586	.9564	.9293	.9611	.9151	.4339	.9140	
				1.50	0.00	.429	.500	.286	.4	0.00	
22			20	.8761	.8997	.8965	.8845	.9029	.8951	.8748	
				.500	0.00	.571	.666	.429	.550	1.50	
23			20	.9347	.9026	.8592	.8887	.8639	.8697	.9182	
				0.00	0.00	.857	.833	1.00	.900	.500	
24			20	.9204	.8843	.8562	.8660	.8475	.8561	.8820	2.0760
				.500	1.00	.571	.500	.714	.600	.500	
Subject 2											
19			20	.8296	.7992	.8112	.8039	.8355	.8175	.8232	
				.500	1.00	1.00	1.50	.714	1.05	.500	
20			20	.8465	.9143	.8805	.8563	.8596	.8659	.8593	
				.500	0.00	1.14	.666	1.14	1.00	0.00	
21			20	.8367	.8379	.8419	.8605	.8405	.8470	.8447	
				0.00	0.00	.286	.332	.714	.45	1.00	
22			20	.7755	.8852	.8250	.8144	.8422	.8278	.8225	
				.500	0.00	.571	.333	.857	.600	.500	
23			20	.7738	.8209	.8081	.8064	.8027	.8057	.8021	
				.500	1.00	.429	.833	.571	.600	1.00	
24			20	.7958	.7940	.7895	.8204	.8184	.8089	.7942	2.2801
				0.00	1.00	.714	.333	.143	.400	.500	
Subject 3											
19			20	1.2599	1.2669	1.2771	1.2597	1.3113	1.2838	1.3584	
				0.00	0.00	0.00	0.00	.143	.05	0.00	
20			20	1.1941	1.2650	1.2580	1.2217	1.2254	1.2357	1.2642	
				1.00	0.00	.143	.167	.429	.250	.500	
21			9	1.2229	1.2186	1.2072	1.1528	1.1731	1.1777	1.2623	
				.500	0.00	0.00	0.00	0.00	.111	0.00	
22			20	1.2324	1.2382	1.1844	1.2096	1.2207	1.2047	1.2524	
				0.00	0.00	.143	0.00	.143	.100	0.00	
23			20	1.1948	1.1439	1.1533	1.1747	1.1604	1.1622	1.1817	
				.500	1.00	.143	.167	.143	.050	.500	
24			20	1.1562	1.1433	1.1033	1.1129	1.1357	1.1175	1.1399	1.6935
				.500	0.00	.429	0.00	.143	.200	0.00	

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery	Info Rate
						Phase 2					
Subject 4											
19			20	.8450	.8982	.8714	.8715	.8796	.8743	.8519	
				1.50	0.00	.857	.667	1.429	1.00	0.00	
20			20	.9073	.9183	.8971	.9116	.9203	.9096	.9121	
				1.00	1.00	.875	.333	.429	.550	0.00	
21			20	.8576	.8863	.8793	.8775	.8743	.8771	.8473	
				.500	1.00	.857	1.333	.857	1.00	.500	
22			20	.8744	.8699	.8701	.8467	.8350	.8508	.8880	
				1.00	0.00	.857	1.167	1.850	1.30	1.00	
23			20	.8995	.8816	.8287	.8268	.8299	.8287	.8123	
				.500	1.00	.714	1.333	1.430	1.100	1.00	
24			20	.8351	.8445	.8310	.8125	.8041	.8160	.7412	2.0487
				.500	0.00	.714	.833	1.00	.850	1.00	
Subject 5											
19			20	.9178	.9006	.8739	.8996	.9041	.8922	.8811	
				0.00	1.00	.286	.333	.571	.400	0.00	
20			20	.8900	.8335	.8919	.9107	.9064	.9025	.8923	
				0.00	1.00	.286	.500	.143	.300	1.00	
21			20	.8524	.8502	.8692	.9102	.8919	.8894	.8900	
				.500	0.00	.571	.667	.286	.500	.500	
22			20	.8575	.8393	.8573	.8650	.8258	.8486	.8528	
				.500	0.00	.143	1.167	.571	.600	0.00	
23			20	.8176	.8115	.8249	.8218	.8462	.8314	.8402	
				.500	1.00	.286	.833	.429	.500	0.00	
24			20	.8929	.8151	.8381	.8296	.8801	.8502	.8744	2.1811
				0.00	0.00	0.00	.333	.429	.250	1.00	
Subject 6											
19			20	.9135	.8441	.8365	.8448	.8547	.8454	.8775	
				.500	0.00	.286	.500	.571	.450	0.00	
20			20	.9007	.8716	.8389	.8562	.8717	.8556	.8508	
				.500	2.00	.286	.167	.429	.300	0.00	
21			20	.8716	.8332	.8290	.8390	.8280	.8317	.8779	
				.500	0.00	.429	0.00	1.00	.500	.500	
22			20	.8561	.8477	.8595	.8424	.8359	.8416	.9016	
				.500	1.00	.286	.167	.286	.250	1.00	
23			20	.8407	.8131	.8139	.8361	.8243	.8242	.7892	
				0.00	0.00	0.00	.500	.714	.400	0.00	
24			20	.8150	.7764	.7792	.8200	.8090	.8012	.8349	2.1729
				0.00	1.00	.714	.333	.571	.600	.500	

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery	Info Rate
					Phase 2						
Subject 7											
19			20	.9195	1.1031	.9371	.9267	.9206	.9282	.9109	
				.500	1.00	.571	.333	.143	.350	0.00	
20			20	.8814	.8975	.8838	.8908	.8773	.8836	.8733	
				.500	0.00	.143	.167	0.00	.100	.500	
21			20	.8928	.8928	.8957	.9084	.9093	.9043	.9107	
				1.00	0.00	.143	.167	.143	.150	.500	
22			20	.9064	.8932	.9021	.9141	.8995	.9048	.8847	2.1059
				.500	0.00	0.00	.167	.286	.150	.500	
Subject 8											
19			20	.7879	.7788	.8051	.7829	.8075	.7993	.8221	
				1.00	0.00	.714	.666	.571	.65	0.00	
20			12	.7856	.8108	.7816	.7897	.7997	.7903	.7835	
				1.00	0.00	1.25	1.00	1.50	1.25	1.00	
21			9	.8128	.7634	.7737	.8078	.7443	.7753	.8100	2.1146
				.500	0.00	.333	.667	.667	.556	1.00	

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery	Info Rate
					Phase 3						
Subject 1											
36	12.64	30	20	.8774	.8604	.8585	.8511	.8519	.8539	.8441	1.9494
				1.50	1.00	.571	1.00	.571	.700	.500	
28	12.64	60	20	.8961	.9186	.8795	.8758	.8611	.8719	.8548	1.7968
				.500	2.00	.857	1.67	.857	1.100	2.00	
42	12.64	90	20	.8764	.8441	.8744	.8278	.8459	.8504	.8713	1.9662
				.500	0.00	1.143	.667	.571	.800	.500	
32	21.07	30	20	.8642	.8672	.8274	.8377	.8502	.8315	.8466	2.0302
				1.00	1.00	.571	.667	.714	.650	1.50	
26	21.07	60	20	.9063	.8538	.8592	.8695	.8228	.8496	.8655	1.7675
				2.50	1.00	1.57	.833	1.143	1.20	.500	
40	21.07	90	12	.8496	.8909	.8594	.8202	.8445	.8414	.8435	2.1704
				1.00	0.00	0.00	.250	.250	.166	1.00	
30	29.49	30	20	.8337	.8568	.8632	.8728	.8402	.8580	.8311	1.8142
				1.00	1.00	1.57	1.00	1.143	1.25	1.50	
44	29.49	60	16	.8826	.8266	.8472	.8475	.8572	.8504	.8475	1.9934
				1.00	0.00	1.00	.500	.600	.688	1.00	
38	29.49	90	4	.8618	.8505	.8363	.8565	.7353	.8160	.8371	2.0150
				.500	2.00	1.00	1.00	1.00	1.00	1.00	
34			20	.8600	.8395	.8391	.8872	.8491	.8570	.9118	1.9262
				.500	1.00	1.00	.833	.714	.850	1.50	
46			20	.8310	.8453	.8355	.8444	.8315	.8368	.8589	1.9938
				1.50	0.00	1.143	.500	.714	.800	0.00	
Subject 2											
41	12.64	30	20	.7685	.7102	.7441	.7687	.7552	.7554	.7516	2.2732
				.500	2.00	1.57	.667	.143	.800	1.00	
33	12.64	60	20	.8445	.7863	.7979	.7729	.7824	.7849	.8042	2.1591
				1.00	1.00	.714	.500	.714	.650	1.00	
27	12.64	90	20	.7845	.7766	.7877	.7931	.7655	.7815	.7707	2.2626
				0.00	1.00	.857	.500	.571	.650	1.00	
25	21.07	30	20	.8530	.7943	.8053	.8034	.8100	.8032	.8313	2.1930
				.500	2.00	.571	.333	.857	.600	.500	
39	21.07	60	20	.7930	.7836	.7504	.7610	.7244	.7445	.7550	2.2885
				0.00	1.00	.714	.667	1.00	.800	1.00	
31	21.07	90	20	.8244	.7576	.7781	.7602	.7657	.7684	.7738	2.2531
				0.00	1.00	.714	.500	1.00	.750	0.00	
43	29.49	30	20	.7767	.7196	.7386	.7363	.7235	.7327	.7675	2.4690
				.500	0.00	.429	.667	.429	.500	0.00	
37	29.49	60	20	.8142	.7692	.7682	.7510	.7516	.7572	.7918	2.2717
				.500	1.00	.571	.833	1.143	.850	0.00	

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery	Info Rate
					Phase 3						
Subject 2, cont.											
29	29.49	90	6	.8173	.7904	.8004	.7855	.7851	.7903	.8037	2.1671
				0.00	1.00	1.00	2.50	1.00	1.50	.500	
34			20	.7921	.8064	.8033	.7838	.7968	.7948	.8161	2.2182
				.500	1.00	.286	.333	.857	.500	.500	
45			20	.7883	.7905	.7843	.7794	.7724	.7787	.8032	2.2705
				.500	1.00	1.143	.333	.857	.800	.500	
Subject 3											
32	12.64	30	20	1.1719	1.1179	1.1855	1.1351	1.1149	1.1457	1.0712	1.6903
				0.00	1.00	.143	.167	0.00	.100	.500	
26	12.64	60	20	1.1843	1.0883	1.1053	1.1354	1.1156	1.1179	1.1929	1.7340
				0.00	0.00	.143	0.00	.143	.100	0.00	
40	12.64	90	20	1.0877	1.0347	1.0395	1.0424	1.0379	1.0398	1.0320	1.8271
				0.00	0.00	.429	0.00	.143	.200	0.00	
28	21.07	30	20	1.1160	1.0910	1.1095	1.1403	1.1314	1.1213	1.1570	1.6800
				0.00	0.00	.143	.333	0.00	.150	1.00	
42	21.07	60	20	1.0592	1.0470	1.0409	1.0374	1.0289	1.0357	1.0139	1.7965
				0.00	1.00	.286	.333	.429	.350	0.00	
38	21.07	90	20	1.1140	1.0812	1.0542	1.0301	1.0151	1.0333	1.0630	1.7524
				.500	0.00	.286	.733	.143	.250	1.50	
36	29.49	30	20	1.1027	1.0914	1.1023	1.1058	1.0596	1.0884	1.0813	1.6927
				1.00	0.00	.143	.167	.571	.300	0.00	
30	29.49	60	20	1.0891	1.1148	1.0912	1.0760	1.0803	1.0828	1.0903	1.6841
				.500	0.00	.143	.667	.286	.350	.500	
44	29.49	90	6	1.0259	1.0092	.9997	1.0239	1.0760	1.0332	1.0576	1.7689
				.500	0.00	.500	.500	.500	.500	0.00	
34			20	1.0441	1.0549	1.0765	1.0926	1.0989	1.0891	1.0988	1.7603
				0.00	1.00	.286	.167	.143	.200	0.00	
46			20	1.0085	1.0029	1.0209	1.0552	1.0395	1.0377	1.0154	1.8670
				.500	0.00	0.00	.167	0.00	.050	.500	

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery	Info Rate
					Phase 3						
Subject 4											
31	12.64	30	20	.8389	.8564	.8340	.8286	.8121	.8247	.8320	2.1454
				0.00	0.00	.571	.500	.286	.450	1.50	
25	12.64	60	20	.9112	.8562	.8319	.8443	.8340	.8364	.8721	1.9819
				.500	1.00	.857	.333	1.500	.850	.500	
39	12.64	90	20	.8732	.8451	.8299	.7828	.7826	.7992	.8283	2.0746
				0.00	0.00	.857	.830	.857	.850	.500	
29	21.07	30	20	.8645	.8250	.8455	.8379	.8446	.8429	.8642	1.9002
				.500	0.00	.857	.833	.857	.850	.500	
43	21.07	60	20	.8173	.8198	.7997	.8009	.7868	.7955	.7791	2.1643
				.500	3.00	1.00	.667	1.00	.900	.000	
37	21.07	90	20	.8352	.7895	.8141	.8111	.7854	.8031	.8118	1.9856
				1.00	1.00	1.14	1.00	1.29	1.15	1.00	
27	29.49	30	20	.8369	.8409	.8192	.8089	.8151	.8147	.8167	2.0393
				0.00	0.00	.429	1.50	.857	.900	.500	
41	29.49	60	15	.8419	.8536	.8131	.7865	.7870	.7955	.7997	2.0566
				1.00	2.00	.800	1.200	.600	.867	.500	
33	29.49	90	6	.8388	.8126	.8356	.8469	.8025	.8283	.8390	2.1631
				.500	0.00	0.00	2.00	.500	.833	0.00	
35			20	.8521	.8146	.8016	.7916	.7900	.7945	.8426	2.1002
				.500	1.00	.286	.667	1.286	.75	0.00	
45			20	.8054	.8182	.8223	.8213	.8016	.8147	.8163	2.1249
				1.00	0.00	.714	.714	.714	.65	.500	
Subject 5											
36	12.64	30	20	.8114	.7898	.8204	.8294	.8186	.8225	.8594	2.0802
				0.00	1.00	.857	.500	1.00	.800	.500	
30	12.64	60	20	.9077	.8123	.8263	.8531	.8490	.8423	.8164	2.1315
				0.00	0.00	.286	.500	.714	.500	0.00	
44	12.64	90	20	.7830	.7413	.8065	.7976	.8421	.8164	.7838	1.9908
				0.00	2.00	.714	1.333	.714	.900	2.00	
42	21.07	30	20	.7603	.7560	.8072	.8235	.8301	.8201	.8226	2.1162
				.500	1.00	.429	.500	.857	.600	1.00	
38	21.07	60	20	.7932	.8171	.7878	.7950	.8040	.7957	.8153	2.1662
				.500	0.00	.571	1.00	.714	.750	0.00	
28	21.07	90	12	.8924	.9000	.8824	.8358	.8226	.8469	.8207	1.9736
				.500	1.00	.500	1.00	1.25	.917	.500	
40	29.49	30	20	.8031	.7522	.7871	.7825	.7574	.7753	.7831	2.1036
				1.50	1.00	.429	1.333	.857	.850	.500	
32	29.49	60	12	.8122	.8448	.8594	.8468	.8116	.8393	.8042	2.0491
				.500	1.00	.250	.500	1.25	.667	1.00	

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery	Info Rate
					Phase 3						
Subject 5, cont.											
26	29.49	90	6	.8295	.8895	.8610	.8546	.7925	.8360	.8514	2.0449
				.500	1.00	.500	0.00	1.500	.667	.500	
34			20	.8695	.7848	.8096	.8516	.8280	.8287	.8472	2.0413
				0.00	0.00	.714	1.00	.429	.350	1.50	
46			20	.8306	.7871	.7794	.7647	.7740	.7731	.7721	2.0342
				1.00	0.00	.428	.833	1.429	.900	1.00	
Subject 6											
29	12.64	30	20	.8425	.7563	.7679	.8055	.7821	.7842	.8037	2.3578
				0.00	1.00	0.00	.500	.429	.300	.500	
39	12.64	60	20	.8017	.7360	.7429	.7768	.7534	.7567	.7759	2.3301
				0.00	1.00	.571	.333	.714	.550	.500	
37	12.64	90	20	.8090	.8015	.7777	.7713	.7569	.7685	.7950	2.2684
				.500	1.00	.857	.667	.571	.700	.500	
25	21.07	30	20	.8747	.8258	.8226	.8222	.8149	.8198	.8243	2.1387
				.5	0.00	.714	.167	.857	.600	0.00	
43	21.07	60	20	.7850	.7351	.7325	.7570	.7475	.7451	.7799	2.3954
				0.00	1.00	.857	.333	.428	.550	0.00	
33	21.07	90	20	.8185	.8090	.8012	.7908	.7734	.7884	.7891	2.23230
				0.00	1.00	.857	.333	.143	.450	0.00	
31	29.49	30	20	.8140	.7698	.7793	.8012	.7884	.7890	.8336	2.3660
				0.00	0.00	.286	.167	.571	.350	0.00	
27	29.49	60	20	.8623	.7584	.8116	.8106	.7793	.8000	.8025	2.1207
				0.00	0.00	.7143	.333	.571	.600	1.00	
41	29.49	90	6	.7776	.7526	.7315	.7276	.7363	.7318	.7695	2.3765
				0.00	0.00	0.00	1.50	1.50	1.00	0.00	
35			20	.8452	.7723	.7794	.8019	.8059	.7954	.8167	2.2039
				0.00	0.00	.429	.833	.571	.550	1.00	
45			20	.7376	.7222	.7464	.7662	.7440	.7515	.7780	2.3332
				0.00	1.00	.714	.333	.857	.650	.500	

Table 10. TSCRT Data (Continued

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery	Info Rate
					Phase 3						
Subject 7											
28	12.64	30	20	.8907	.8698	.8708	.8603	.8534	.8616	.8745	2.2306
				0.00	0.00	.143	.167	.143	.150	0.00	
42	12.64	60	20	.8217	.8242	.8011	.8215	.8092	.8101	.8044	2.2639
				0.00	1.00	.286	.500	.286	.350	.500	
36	12.64	90	20	.8272	.8366	.8397	.8516	.8273	.8390	.8545	2.2726
				.500	1.00	0.00	.333	.268	.200	0.00	
26	21.07	30	20	.9124	.9026	.8950	.8945	.8722	.8869	.8766	2.1450
				.500	0.00	0.00	0.00	.429	.150	0.00	
40	21.07	60	20	.8550	.8502	.8263	.8319	.8165	.8246	.8640	2.2573
				0.00	0.00	.286	.333	.429	.350	0.00	
32	21.07	90	12	.8753	.8303	.8324	.8612	.8360	.8431	.8371	2.3182
				.500	0.00	.250	0.00	0.00	.083	.000	
44	29.49	30	20	.8821	.8024	.8301	.8497	.8222	.8332	.8351	2.2405
				.000	0.00	.429	.167	.143	.250	.500	
38	29.49	60	15	.8521	.7892	.8080	.7994	.7842	.7972	.8464	2.2047
				.500	0.00	.200	.400	.800	.467	.500	
30	29.49	90	6	.8810	.8606	.8657	.8301	.8400	.8453	.8838	2.0671
				0.000	0.00	0.00	.500	2.00	.83	.500	
34			20	.8413	.8401	.8671	.8559	.8555	.8579	.8585	2.1738
				0.00	0.00	0.00	.333	.143	.150	1.50	
46			20	.8477	.8367	.8169	.8347	.8247	.8259	.8430	2.3836
				0.00	0.00	0.00	.167	0.00	.050	0.00	

Table 10. TSCRT Data (Continued)

Session	Force (Lbs)	Rate (RPM)	Exercise Sets	Pre-Exercise	Initial Exercise	First Third Exercise	Second Third Exercise	Third Third Exercise	Total Exercise	Recovery	Info Rate
					Phase 3						
Subject 8											
33	12.64	30	20	.8051	.7593	.7719	.7789	.7673	.7724	.7816	2.2603
				.500	2.00	.857	.333	.429	.550	.500	
27	12.64	60	20	.8291	.7635	.7807	.7996	.7789	.7857	.7866	2.0294
				.500	1.00	.857	1.33	.857	1.00	1.00	
41	12.64	90	20	.7833	.7014	.7262	.7370	.7334	.7319	.7370	2.5003
				0.00	1.00	.286	.500	.286	.350	0.00	
39	21.07	30	20	.8200	.7469	.7483	.7611	.7408	.7495	.7499	2.3460
				0.00	1.00	.286	1.00	.714	.650	1.00	
31	21.07	60	20	.7881	.7081	.7496	.7700	.7421	.7531	.7544	2.3705
				0.00	1.00	.286	.833	.714	.600	0.00	
25	21.07	90	20	.7850	.8432	.7990	.7900	.7855	.7916	.7883	2.1351
				.500	0.00	1.00	1.00	.429	.800	1.50	
37	29.49	30	20	.8193	.7728	.7614	.7774	.7374	.7578	.7946	2.3444
				0.00	0.00	.429	.667	.286	.450	.500	
29	29.49	60	20	.8095	.7474	.7615	.7922	.7714	.7742	.7951	2.2236
				0.00	1.00	.833	.667	.857	.750	0.00	
43	29.49	90	20	.7380	.6816	.6915	.6783	.6755	.6818	.7166	2.4501
				1.00	1.00	.500	1.00	1.00	.830	.500	
35			20	.7951	.7543	.7597	.7881	.7619	.7690	.8444	2.3934
				.500	1.00	.429	0.00	.429	.300	0.00	
45			20	.7650	.7344	.7324	.7295	.7263	.7294	.7686	2.5058
				.500	0.00	.286	.333	.429	.350	0.00	

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